

# Characterize a Habitable Planet

## SAG-4

WHAT to measure  
with WHAT accuracy ?

Lisa Kaltenegger, MPIA/Harvard  
EXO-PAG mtg, Jan. 9, 2011

# SAG 4: Science: modeling ( $\lambda$ )

1) derive accuracy of parameters needed to characterize

- Earth (HZ)
- Super-Earth (HZ)

2) use “standard” models (Earth and Super-Earth)

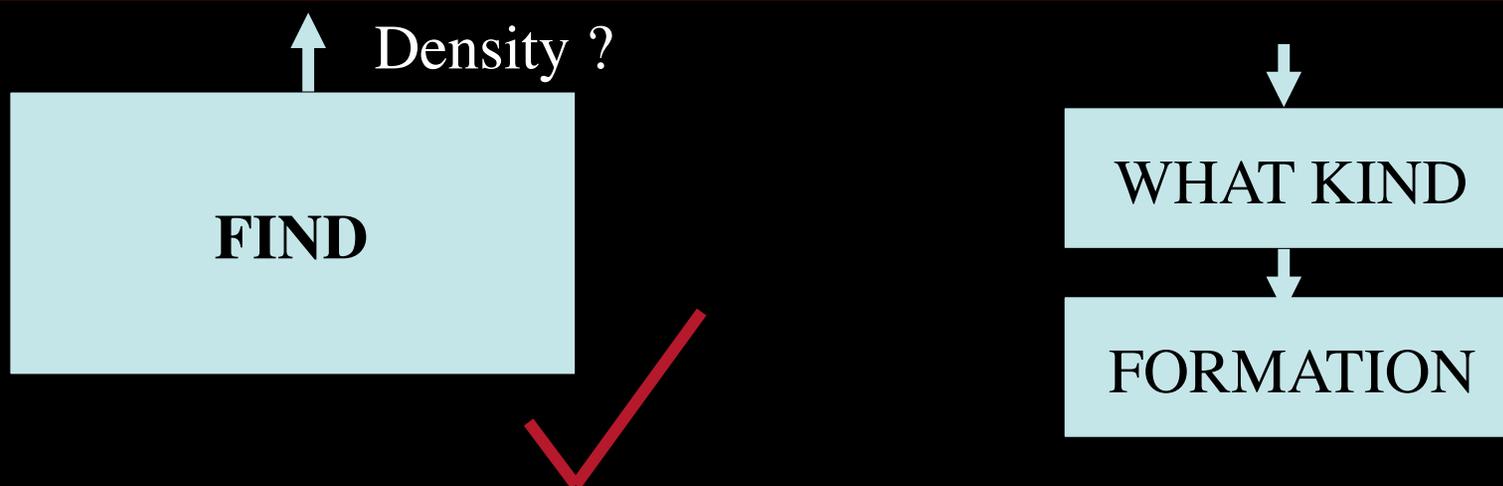
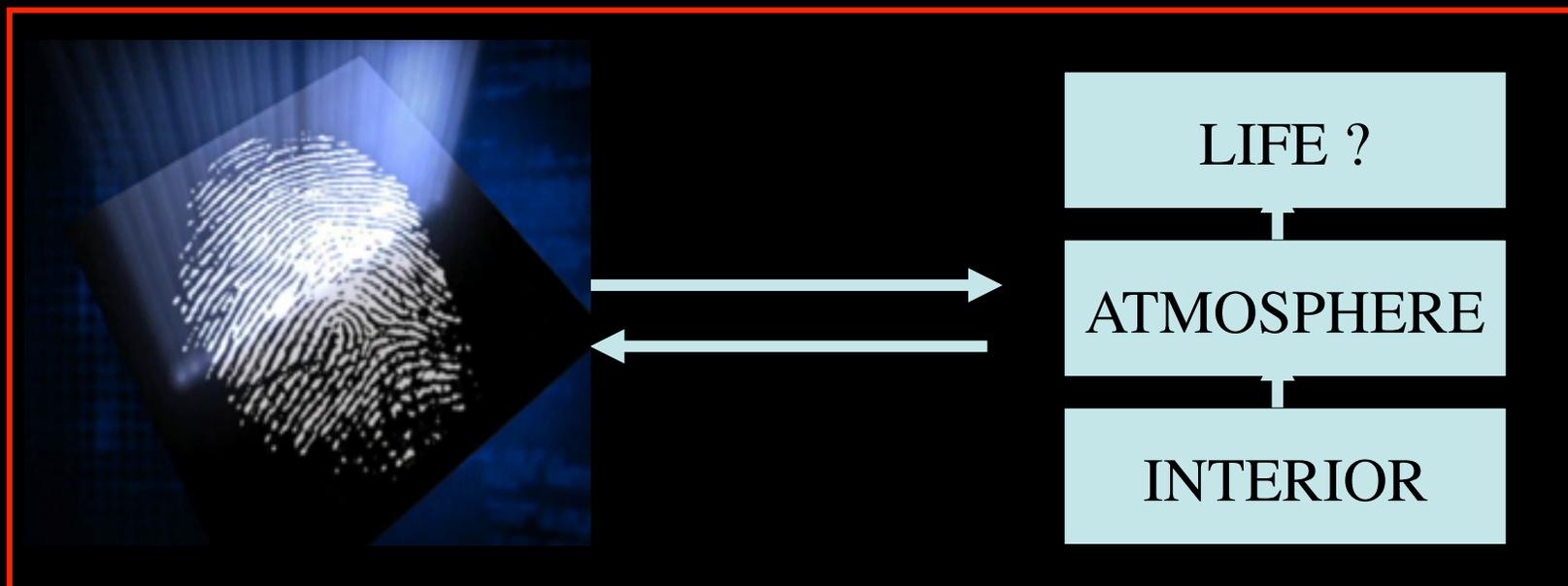
- to compare models of different groups
- generate "standard" spectra as input for designs
- to compare models of different groups

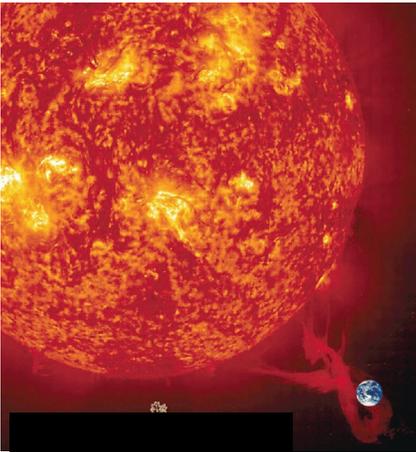
3) deliverables:

- report on spectral features (Earth & Super-Earth)
- report on parameter accuracy needed ( $\lambda$ )
- spectra as input for studies & e.g. SAG 7 & 8

KICK-off – collaboration of modeling teams & lively discussion

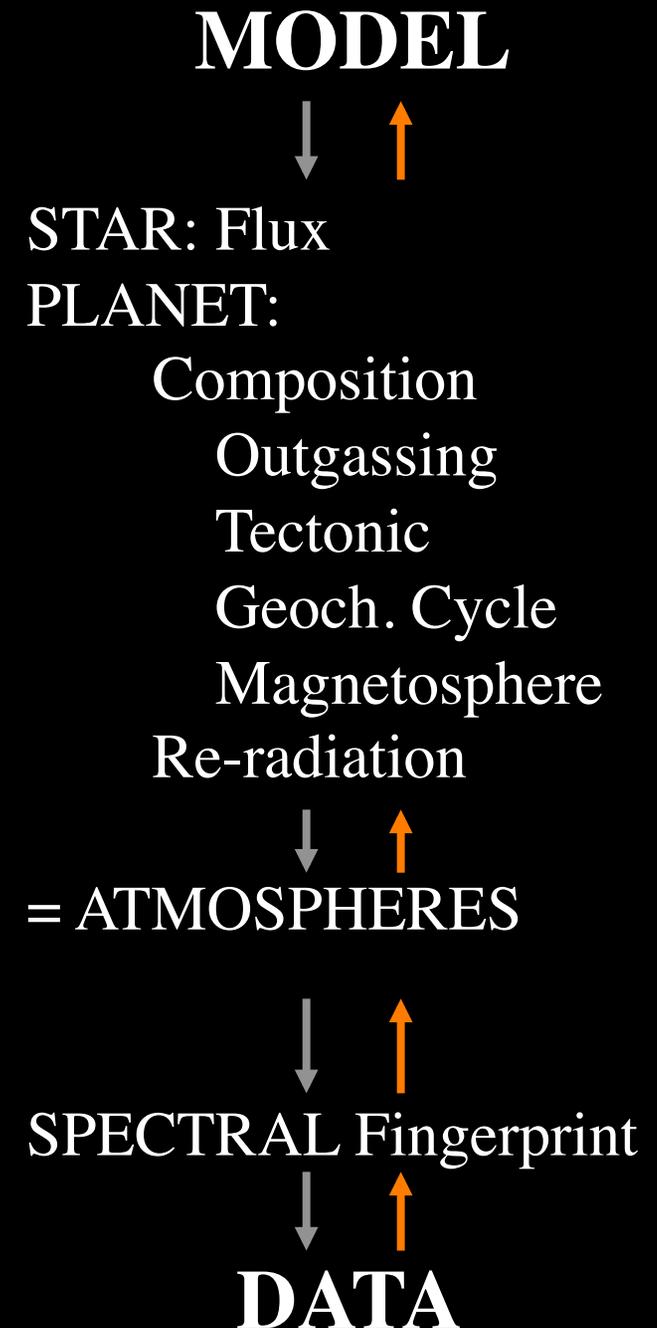
# The IDEA: Line of Evidence

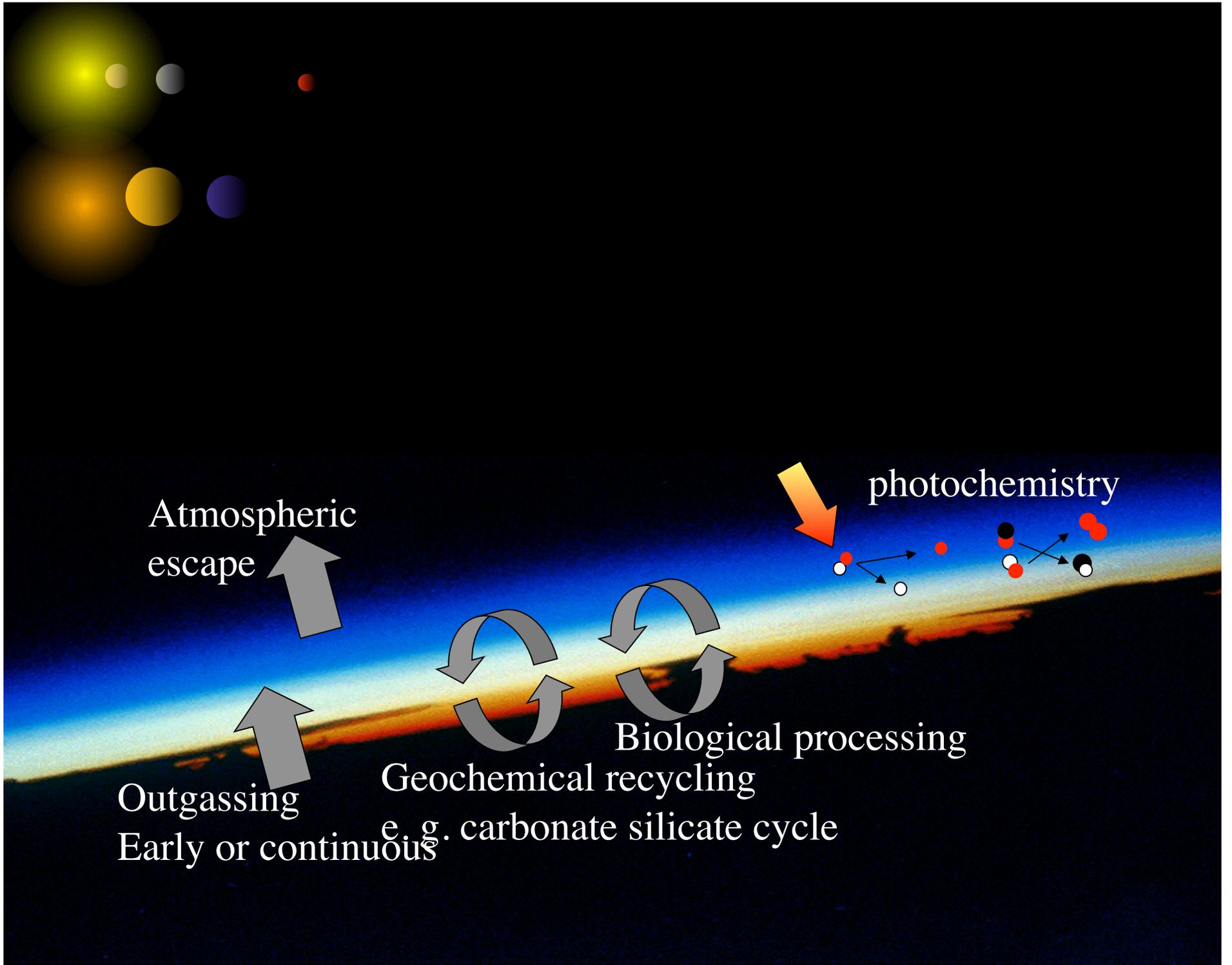




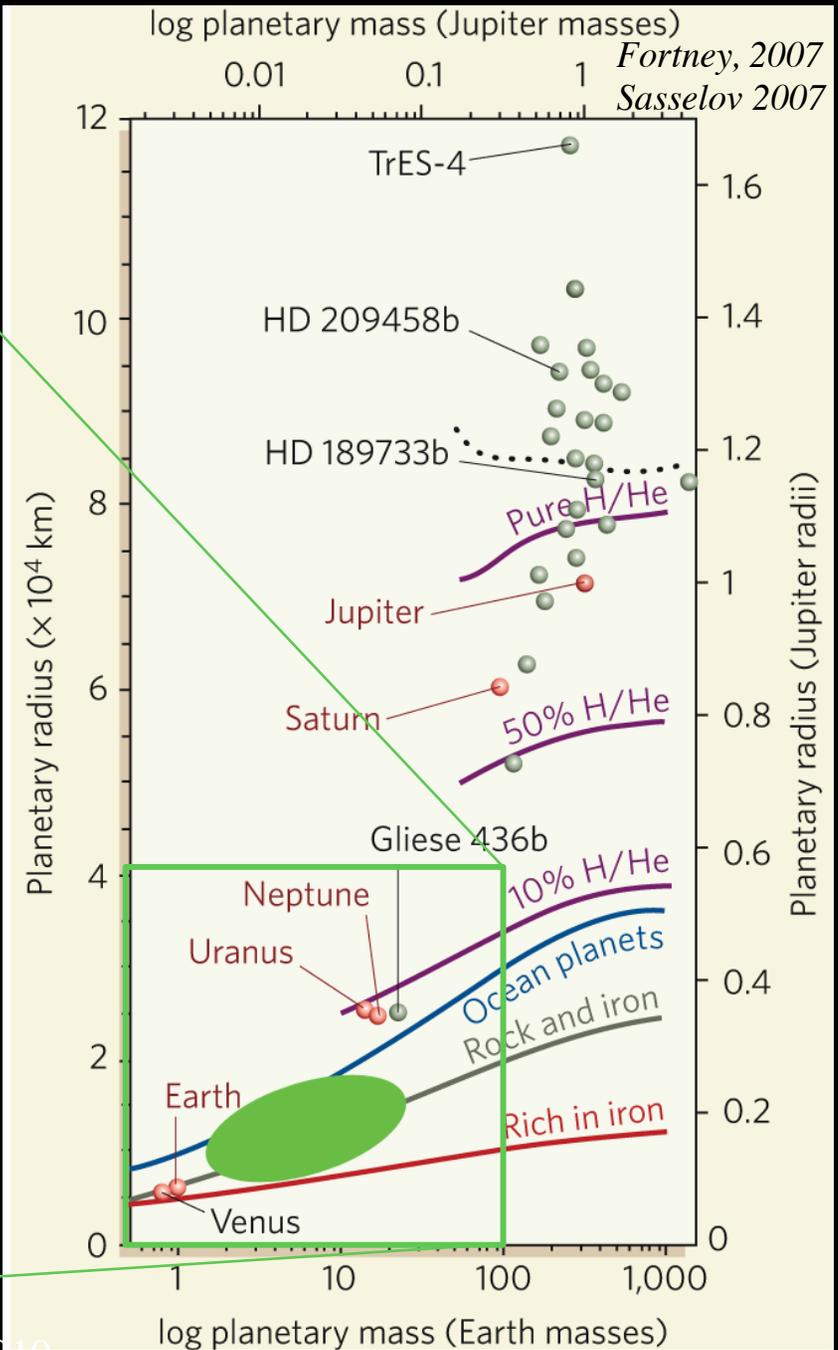
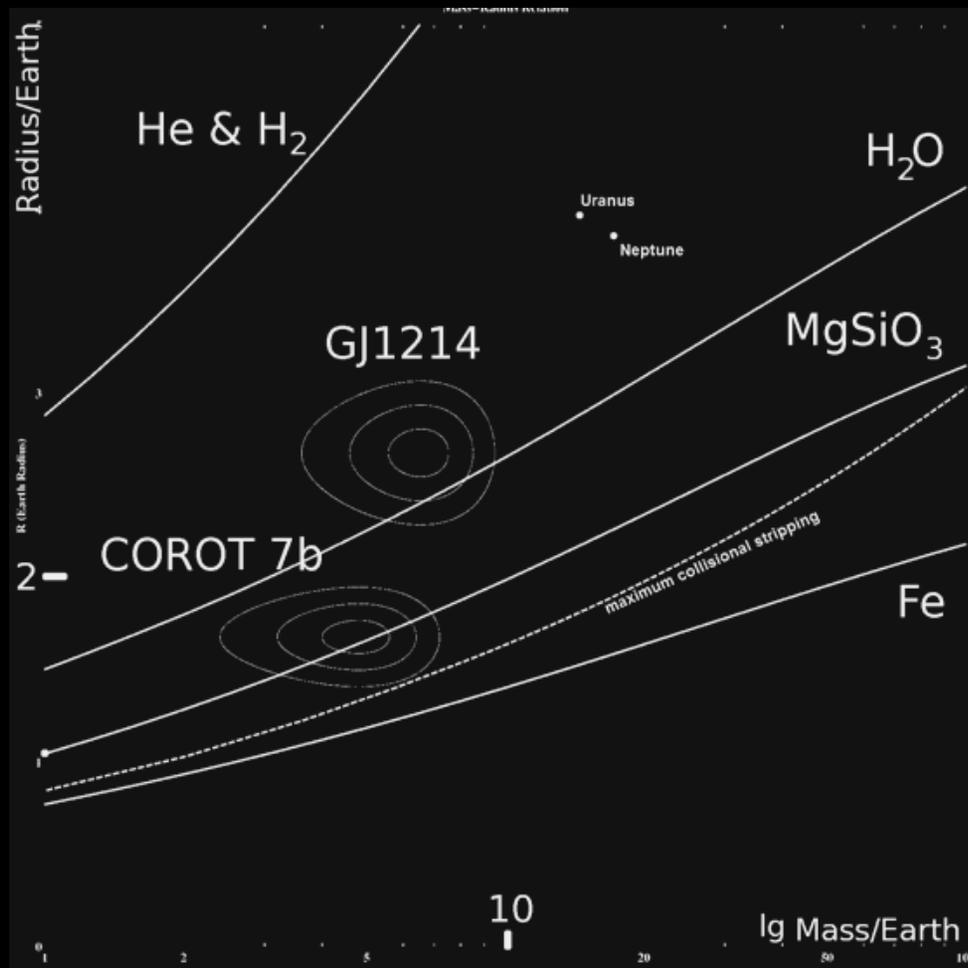
# SAG 4:

- 1) derive accuracy to characterize
  - Earth (HZ)
  - Super-Earth (HZ)
- 2) define “standard” models
  - to compare models





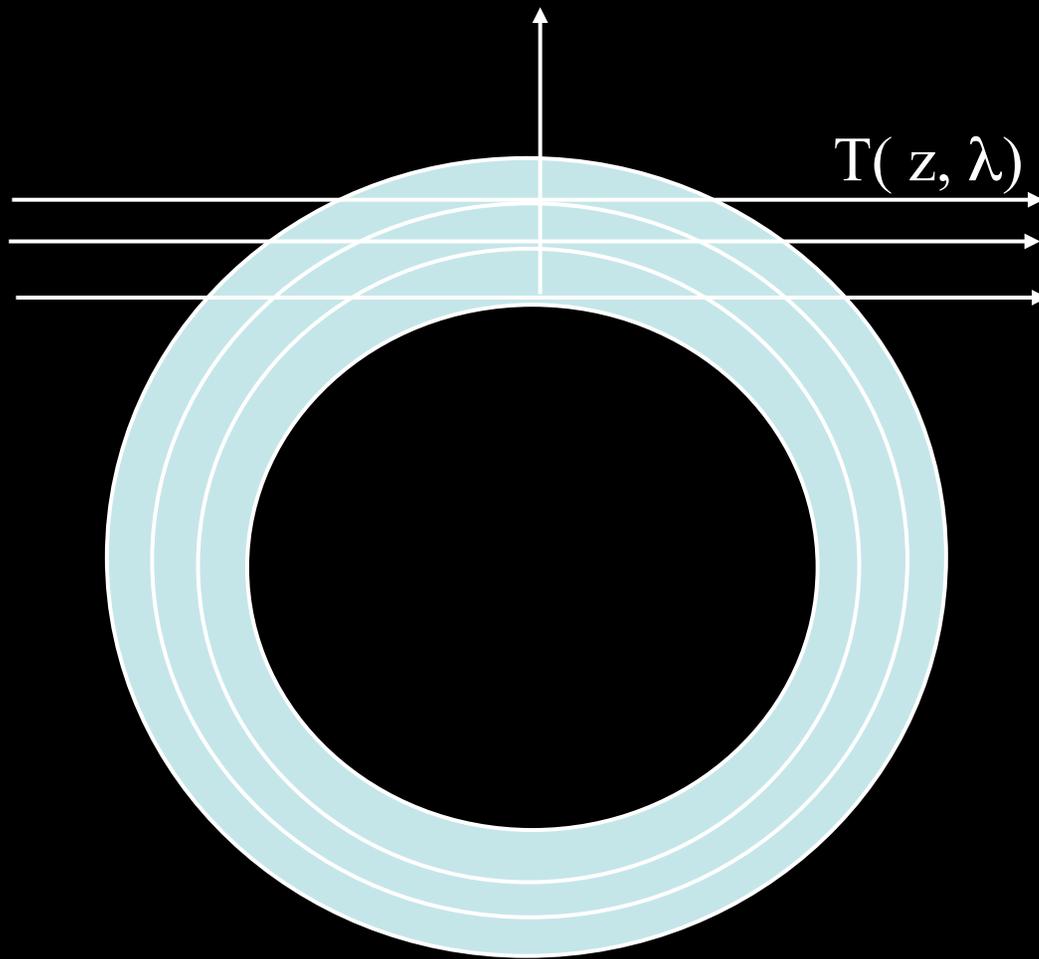
# RV & Transits: density



Zeng & Sasselov (2010), Valencia et al. 2010, Sotin et al. 2010,

# Transit Geometry

$$h \approx T / (g \mu)$$



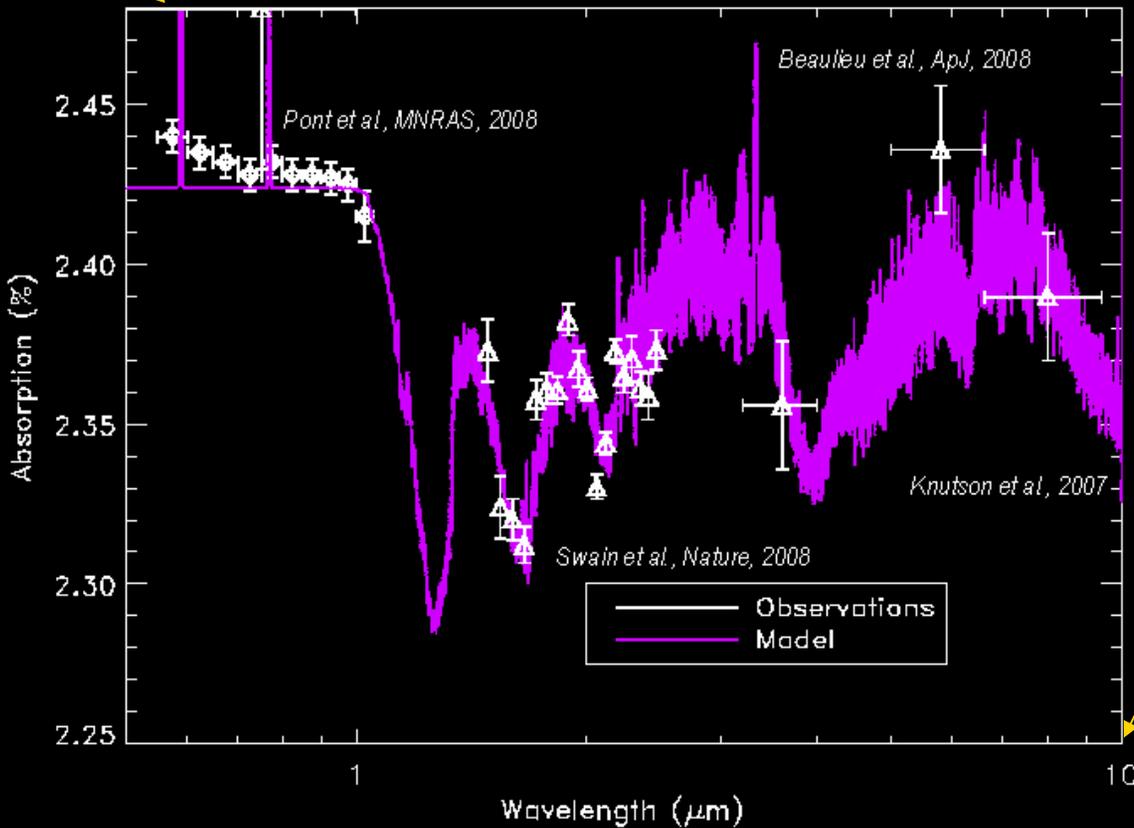
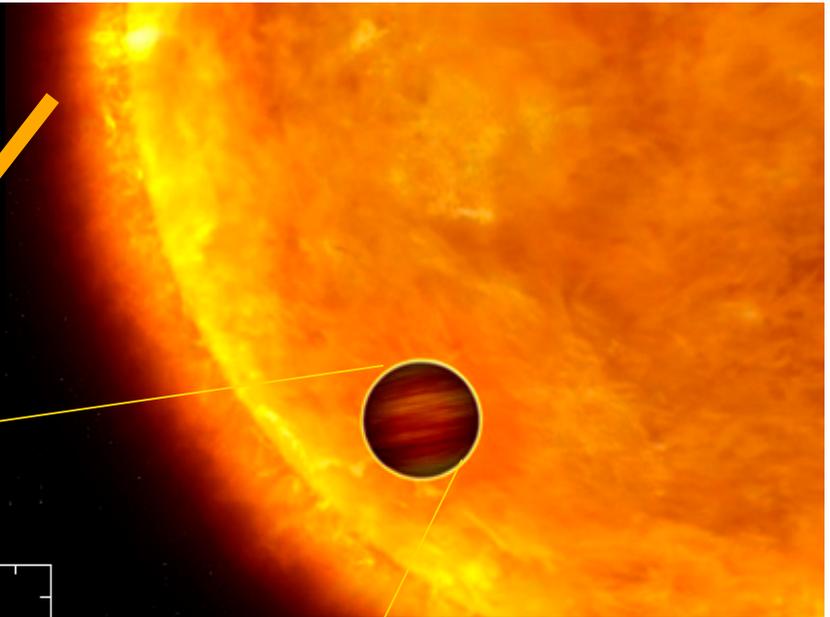
$h$  is the effective height of an opaque atmosphere:

$$h(\lambda) = \int (1-T) dz$$

So

$$R(\lambda) = R_0 + h(\lambda)$$

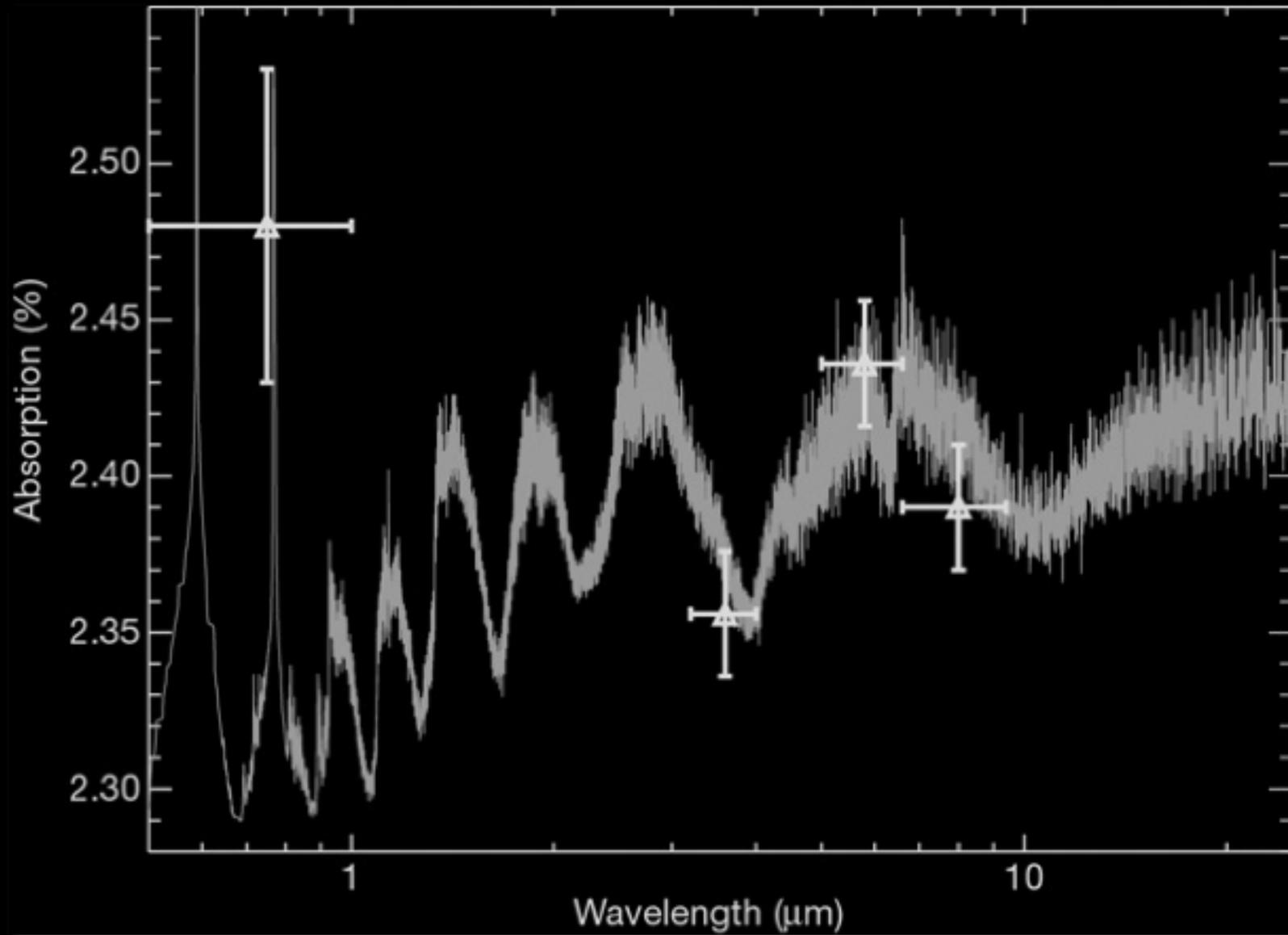
# Explore Planets - EGP ✓



2007 +

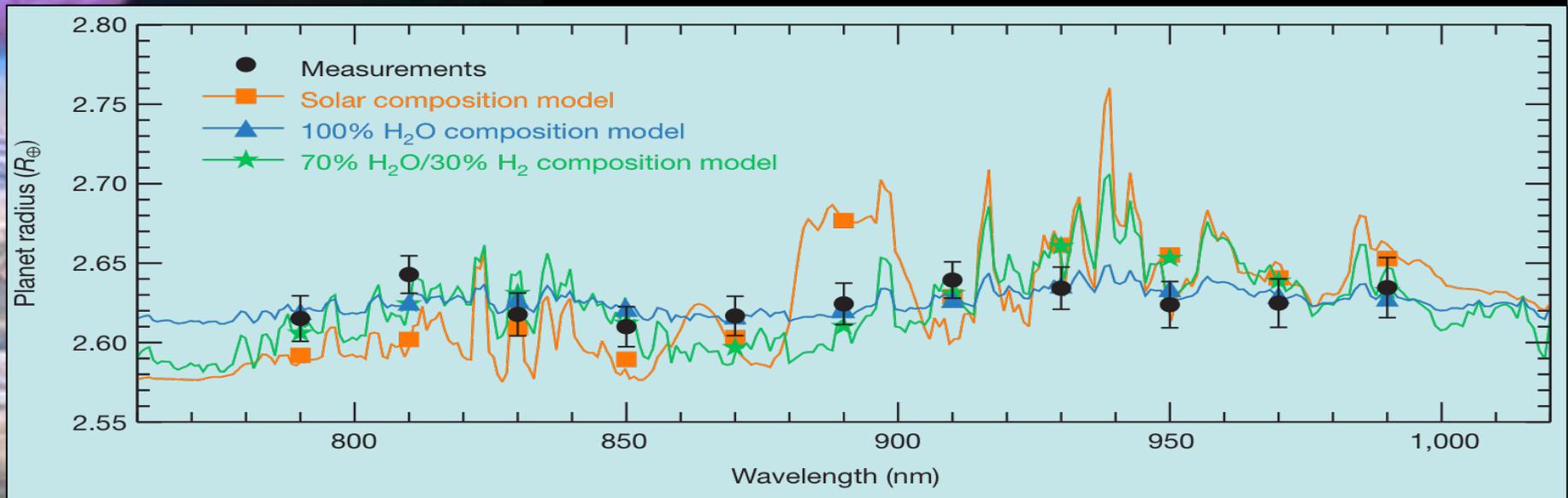
Atmosphere by transits...  
HD189733b (Tinetti07, Swain08)  
Earth (Palle 09, Kaltenegger 09)

# Water in HD 189733b



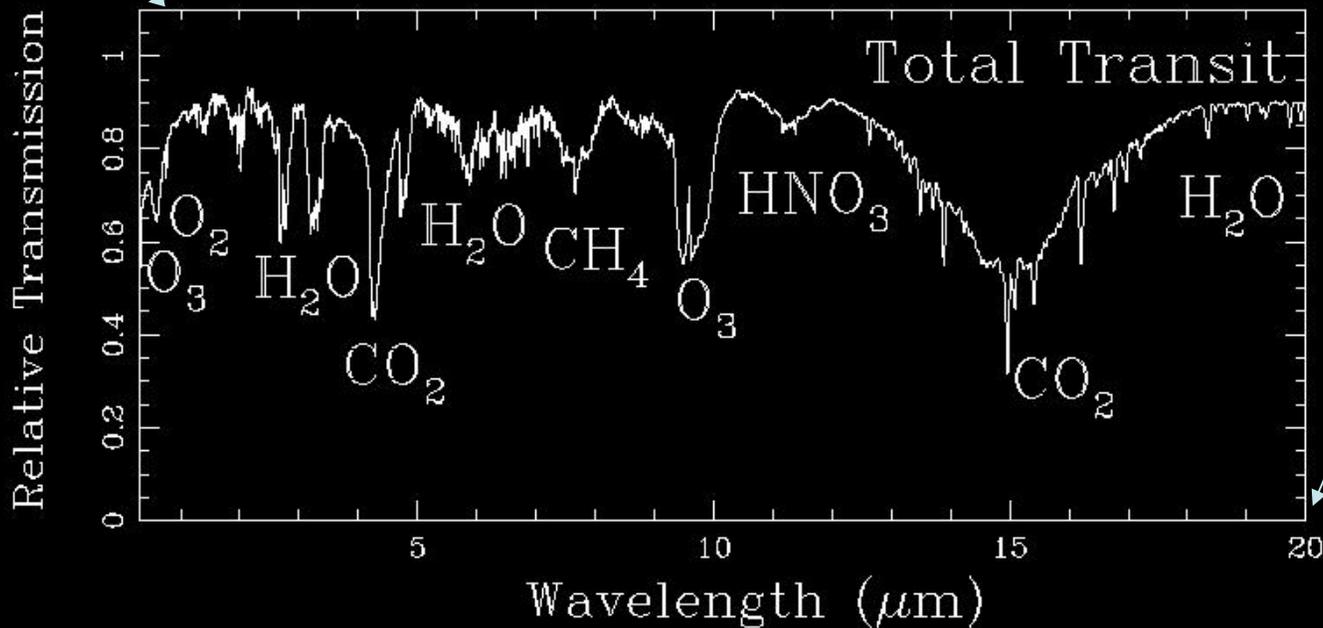
*Tinetti et al. (2007)*

# GJ 1214 - Spectrum



NOT Earth-like (R, M)  
Not a CLEAR H/He atm (spectrum)

# Earth Primary Transit: collect transmitted starlight



$$\text{SNR} = N^{1/2}(\text{tot}) * 2\pi R_p h / \pi R_s^2$$

*Kaltenegger & Traub ApJ 2009*  
*Palle et al. Nature 2009*  
*Data: ATMOS B. Irion 2002*

2002/2014+ ?

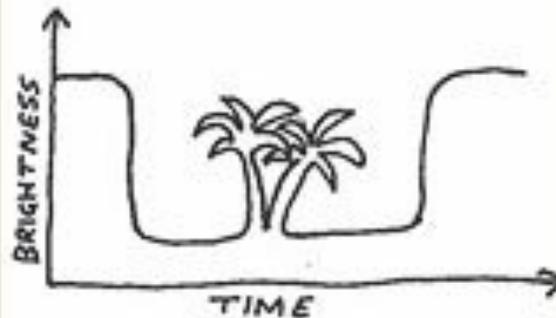
# Habitable Planets with transits = Easy



THE LIGHTCURVE FOR A  
TRANSITING PLANET  
LOOKS LIKE THIS

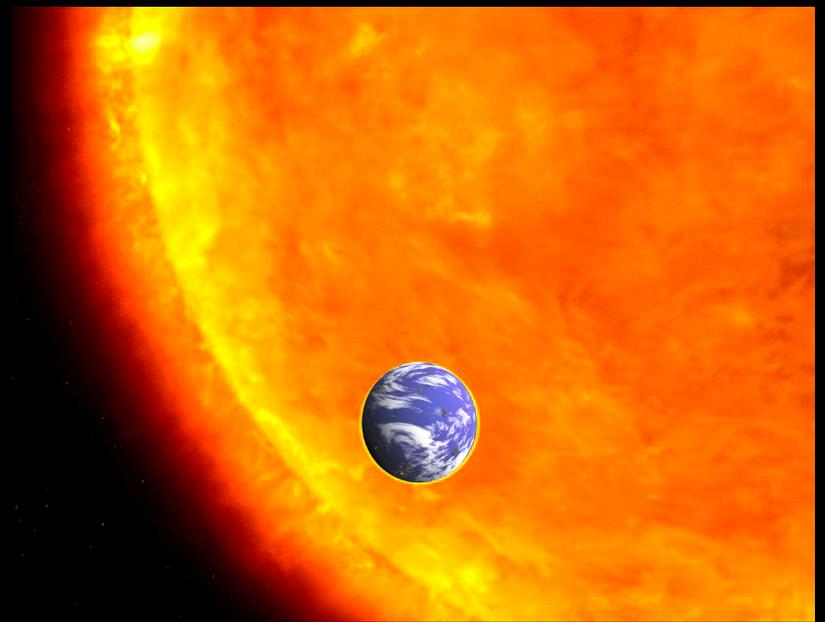
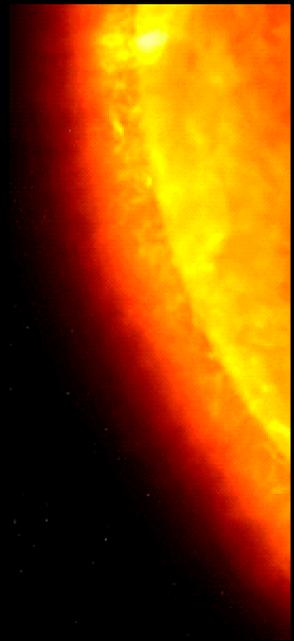


FOR A HABITABLE PLANET  
IT LOOKS LIKE THIS



FOR AN INHABITED PLANET  
IT LOOKS LIKE THIS





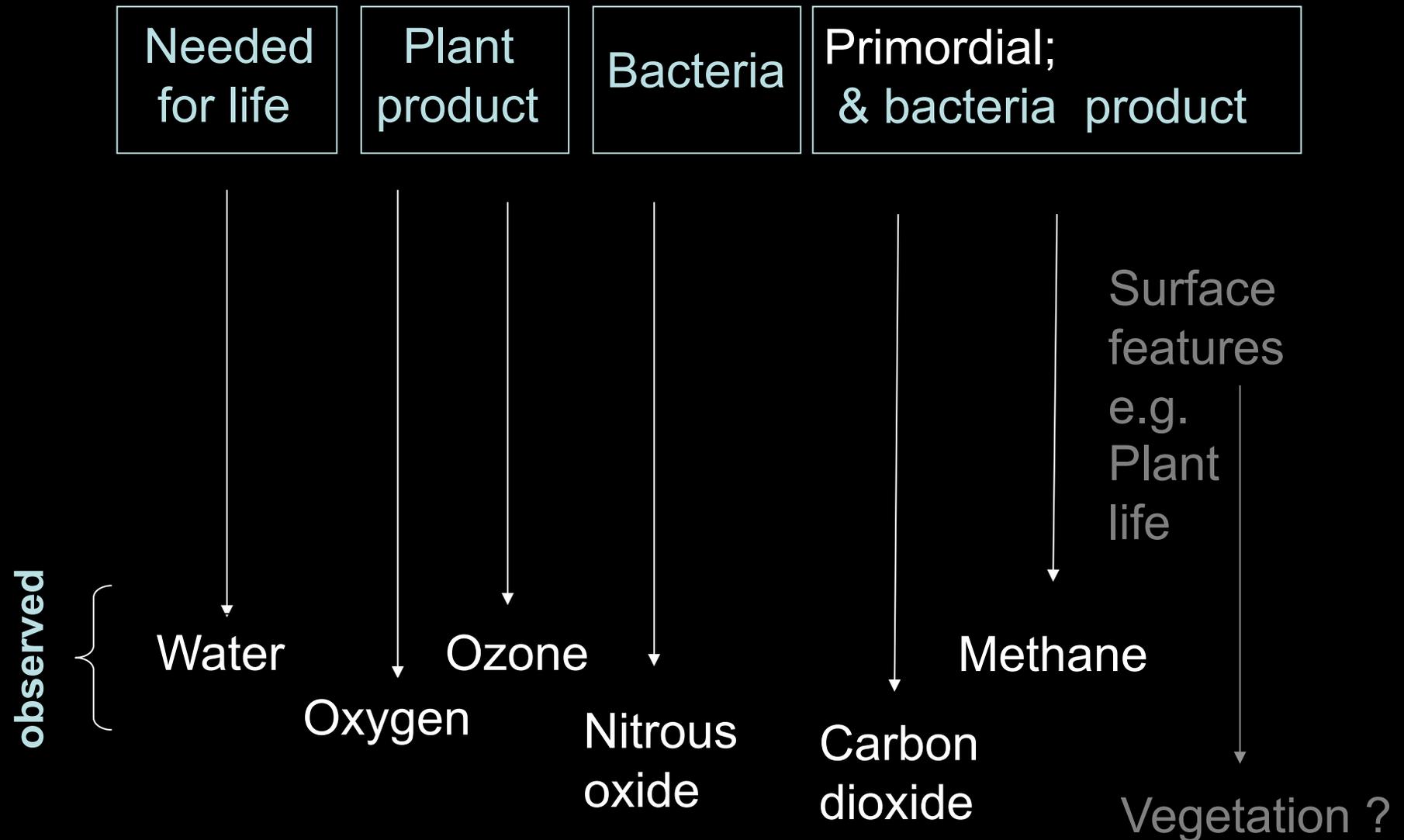
NEXT STEP

The TEST =  
observations

The Pale Blue Dot  
Voyager image, 4 bil. km



# Signs Of Life On An Earth-like Planet



*Adapted from Traub*

# Signs Of Life On An Earth-like Planet

Ozone & Methane (or other reducing gas) **Biomarker**  
Oxygen  
Nitrous oxide

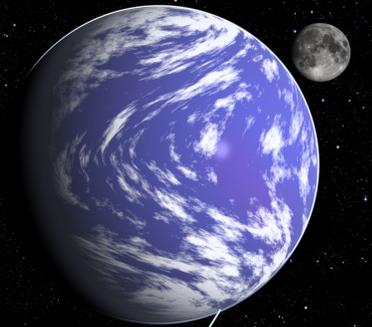
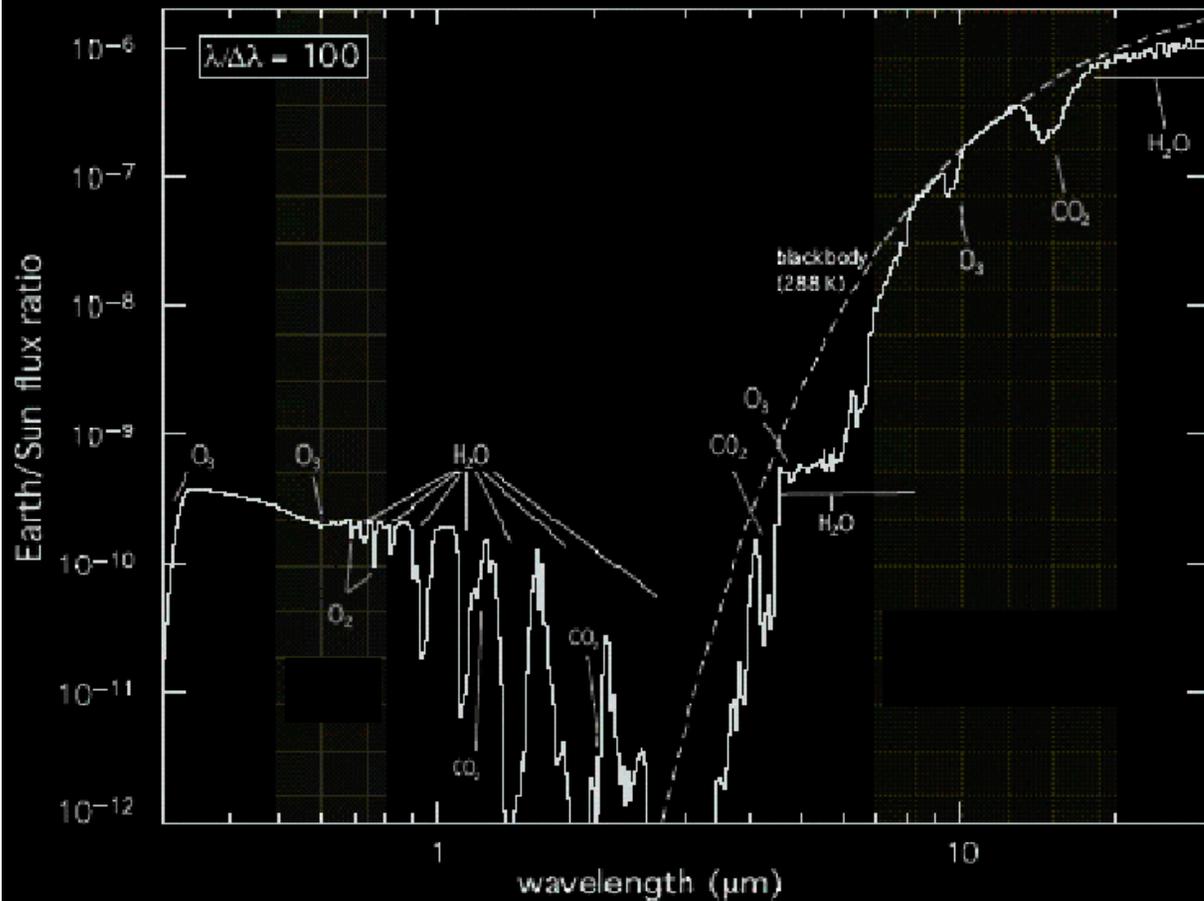
Water makes Oxygen – WITHOUT life

Carbon dioxide - greenhouse & HZ extend

Vegetation – good enough SNR per 1/20 of planet's rotation  
to detect surface feature

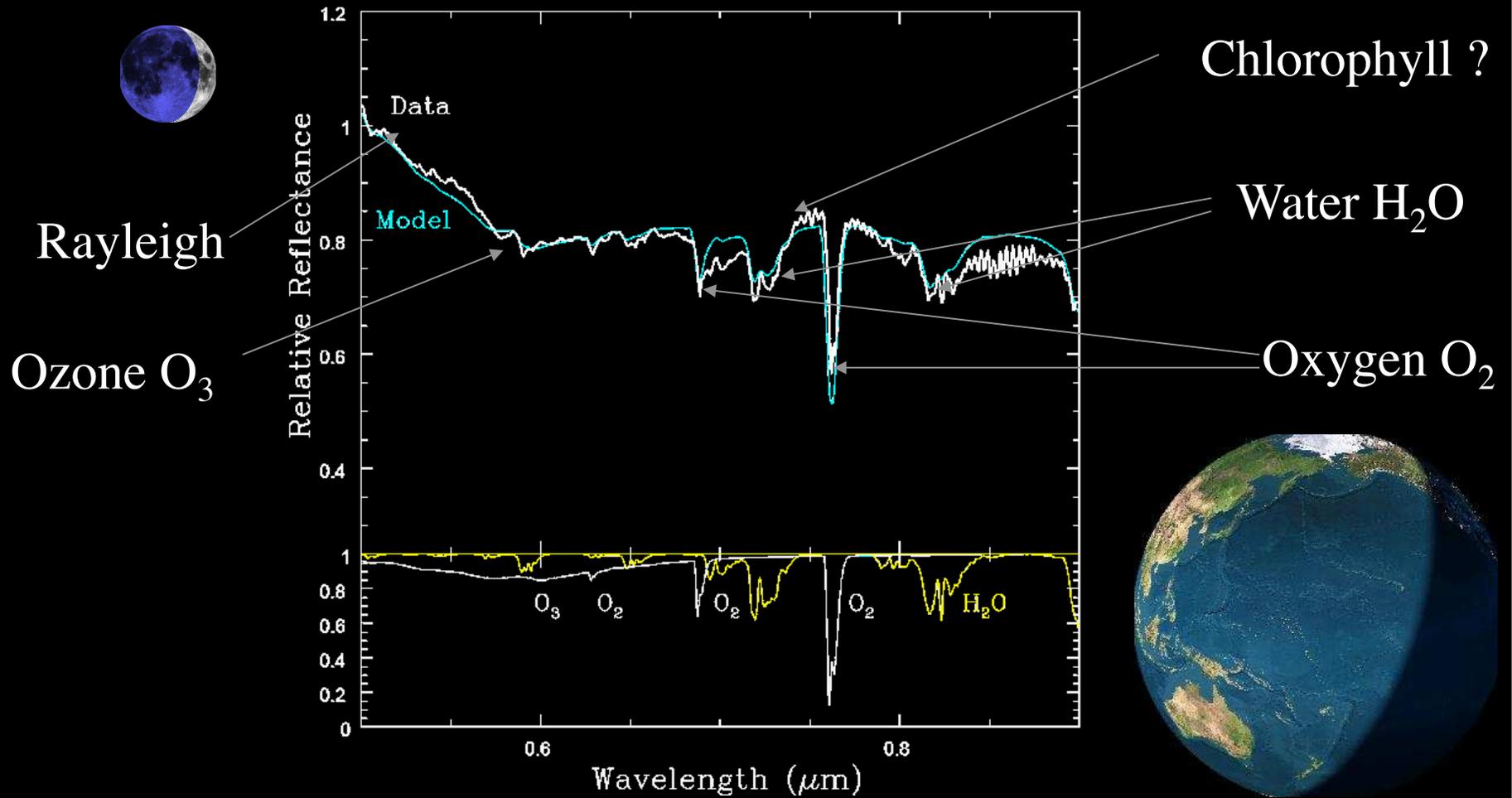
# Direct Imaging & Secondary Eclipse

$$\sim R_{pl}^2$$



*Direct imaging*

# Visible spectrum of Earth

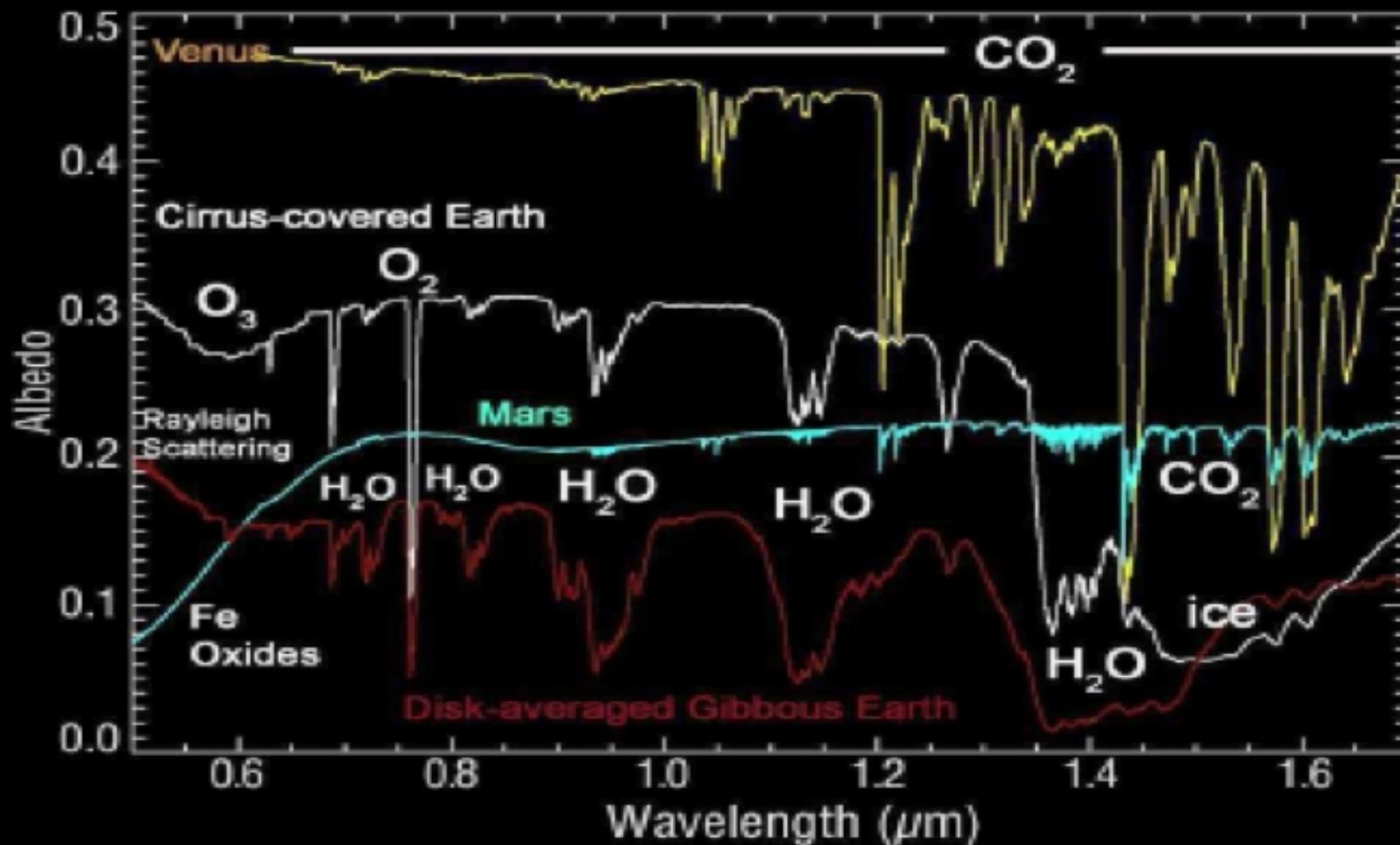


**Observed Earthshine, reflected from dark side of moon.**

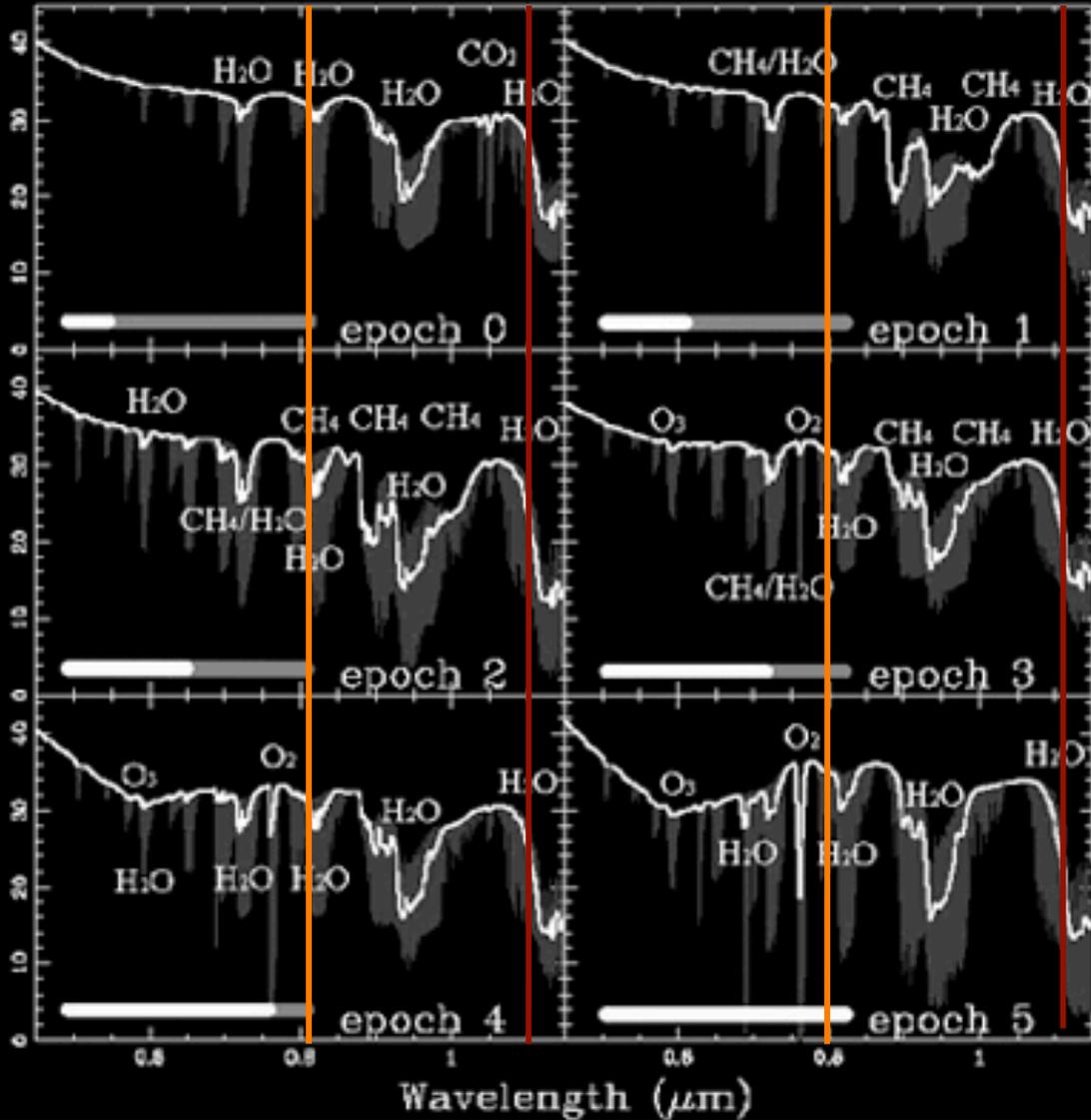
Ref.: Kaltenegger et al 2007, ApJ 574, 2007

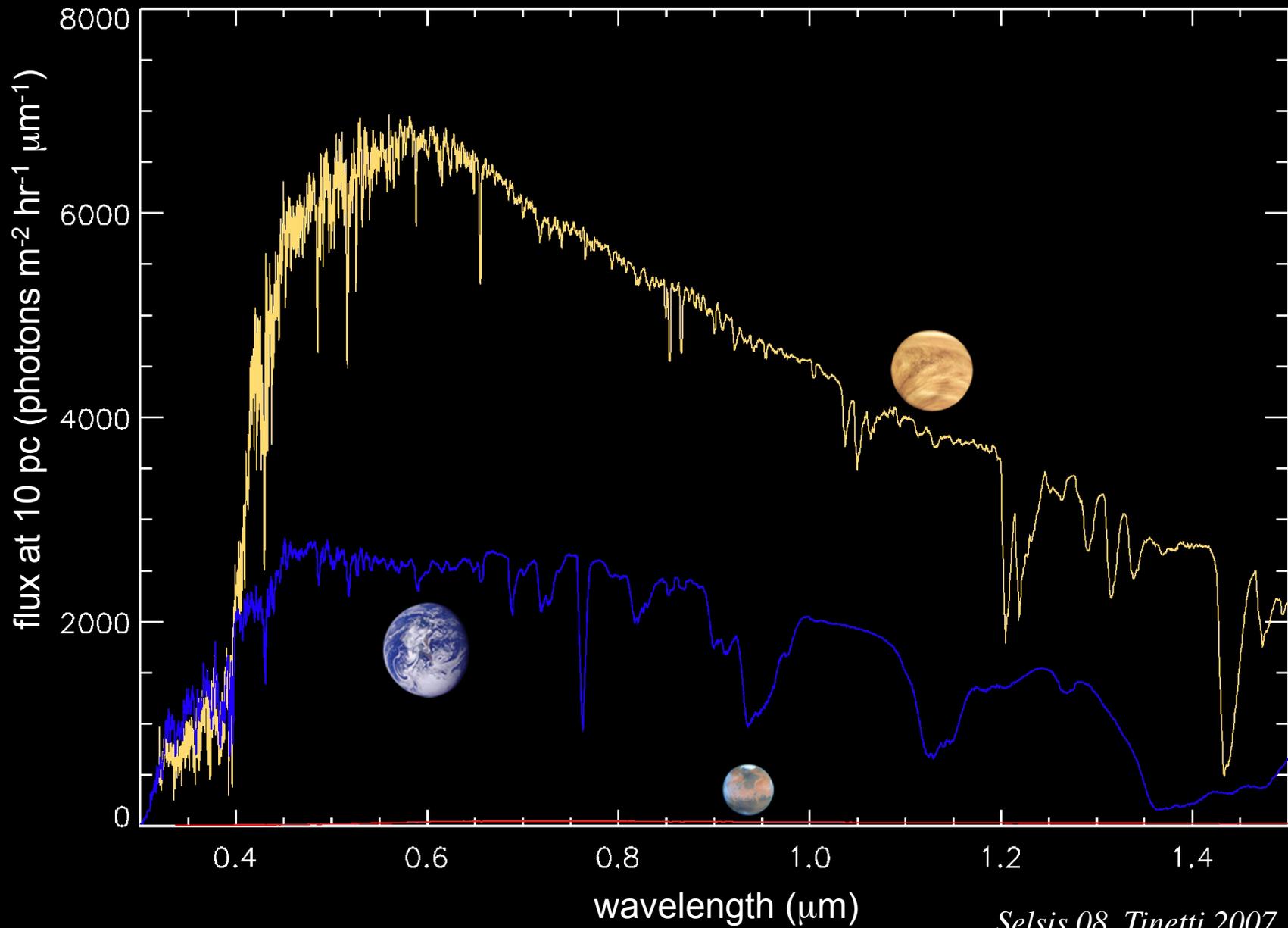
see also e.g.: Montanez-Rodriguez 2005, 07, Arnold 2002, 06, 09; Turnbull 06

# VIS & near-IR: Reflected light



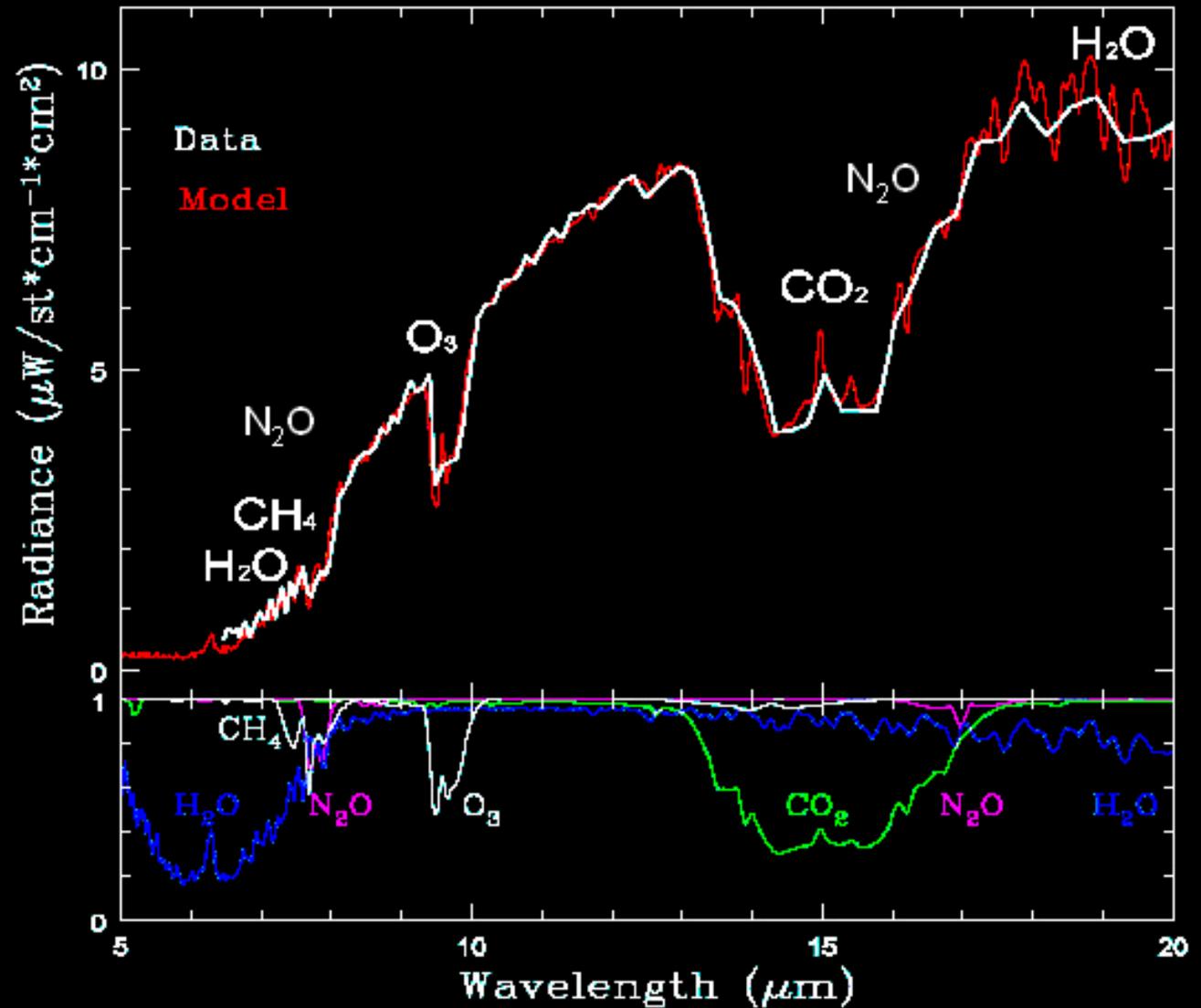
# Earth Evolution over geological time - CSI





*Selsis 08, Tinetti 2007*

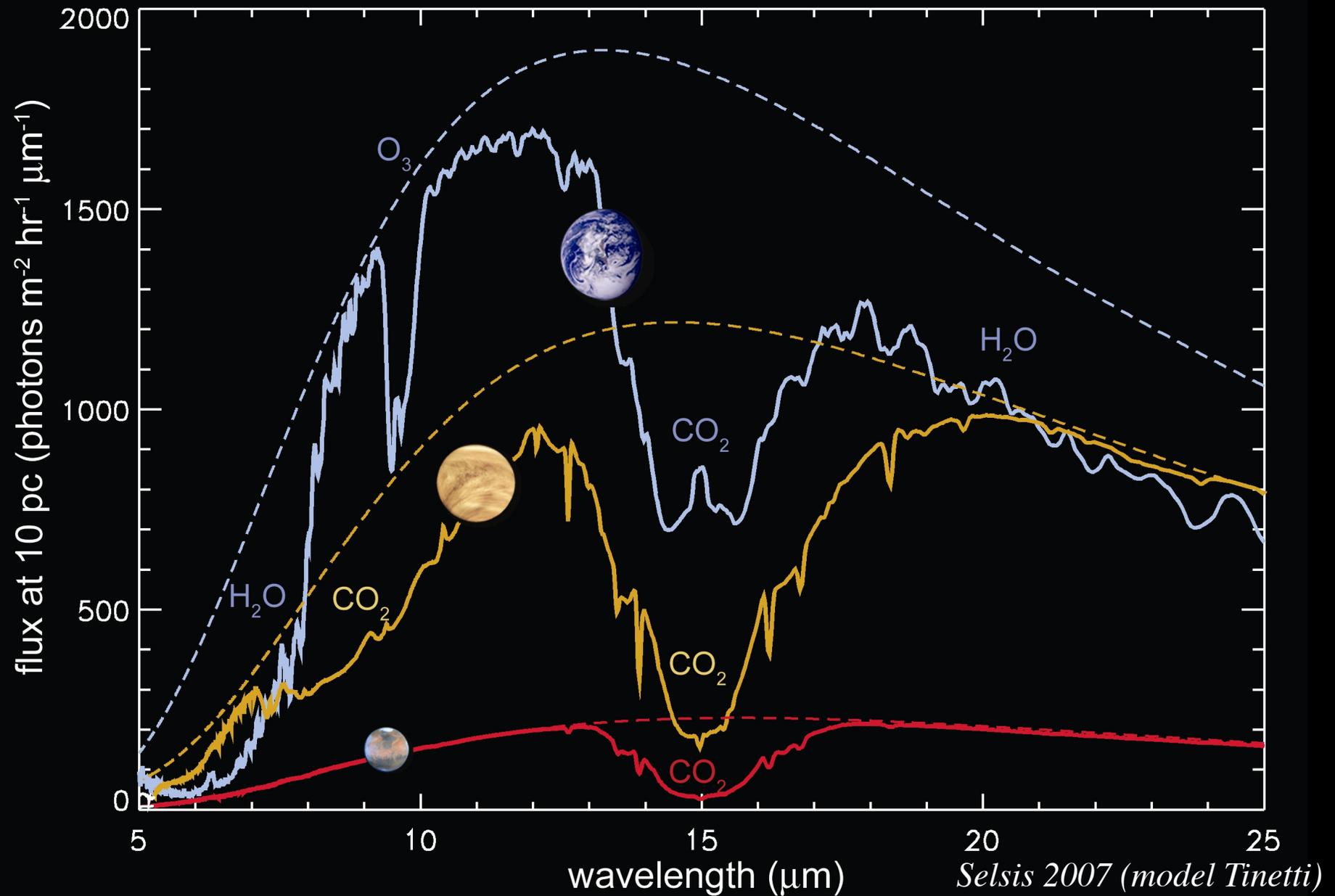
# Earth IR-emission



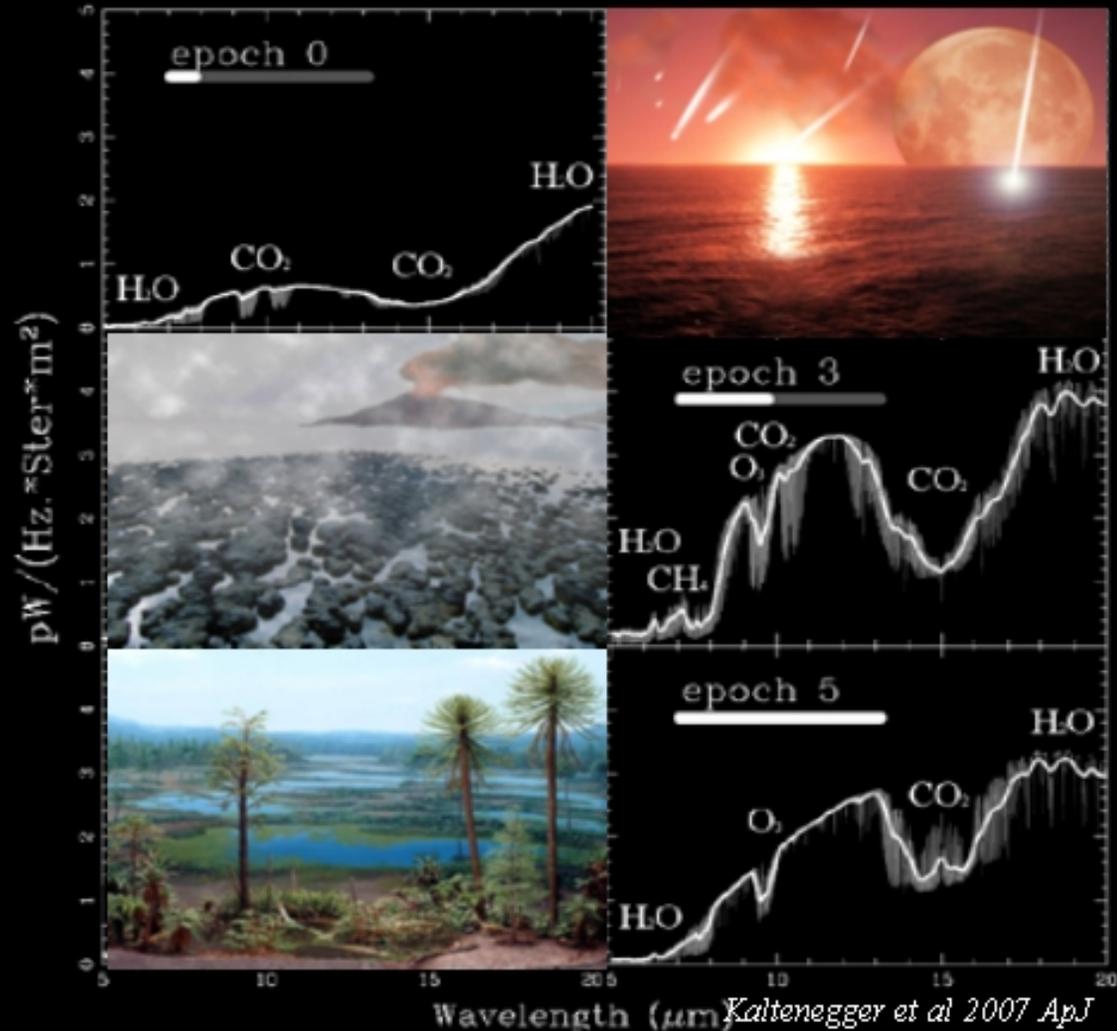
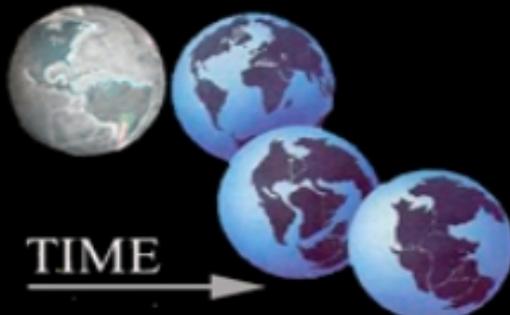
*Kaltenegger, Traub, Jucks 2007 (ApJ)*

*TES data; Christensen 2004*

# Features: 1) observables & 2) unique ?



# Earth Evolution over geological time - CSI



mid IR (5-20 $\mu\text{m}$ ): Res = 25

*Kaltenegger et al 2007 ApJ*



Different evolution  
state / age / mass / etc.

THE TEST:

GRID of Spectra of  
different planets

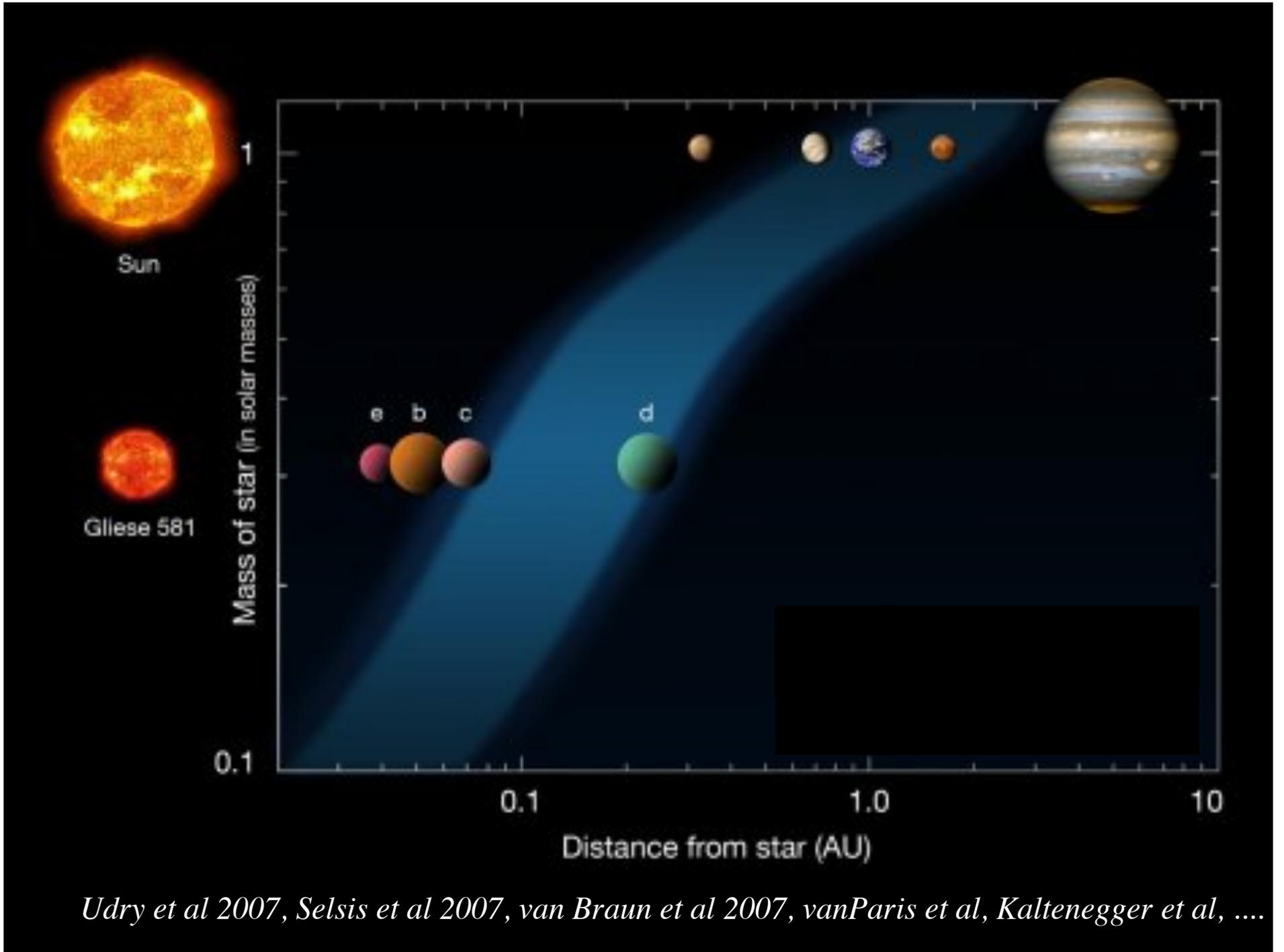
– Exoplore underlying  
physics

- Unique?

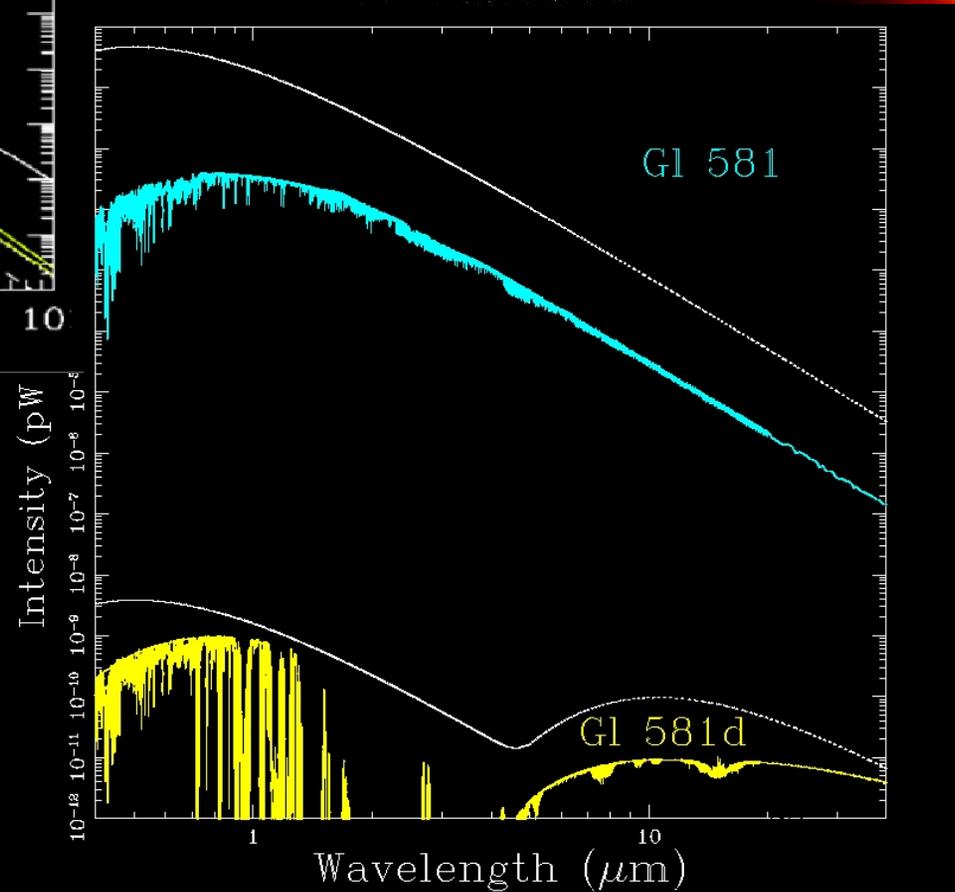
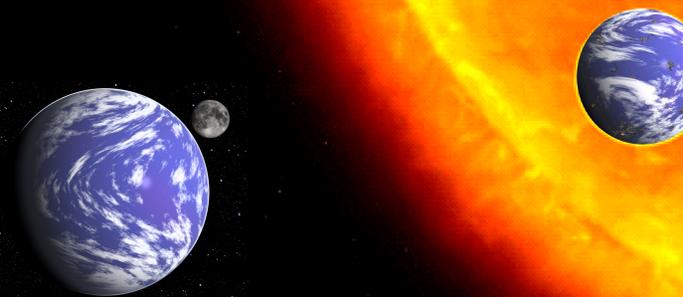
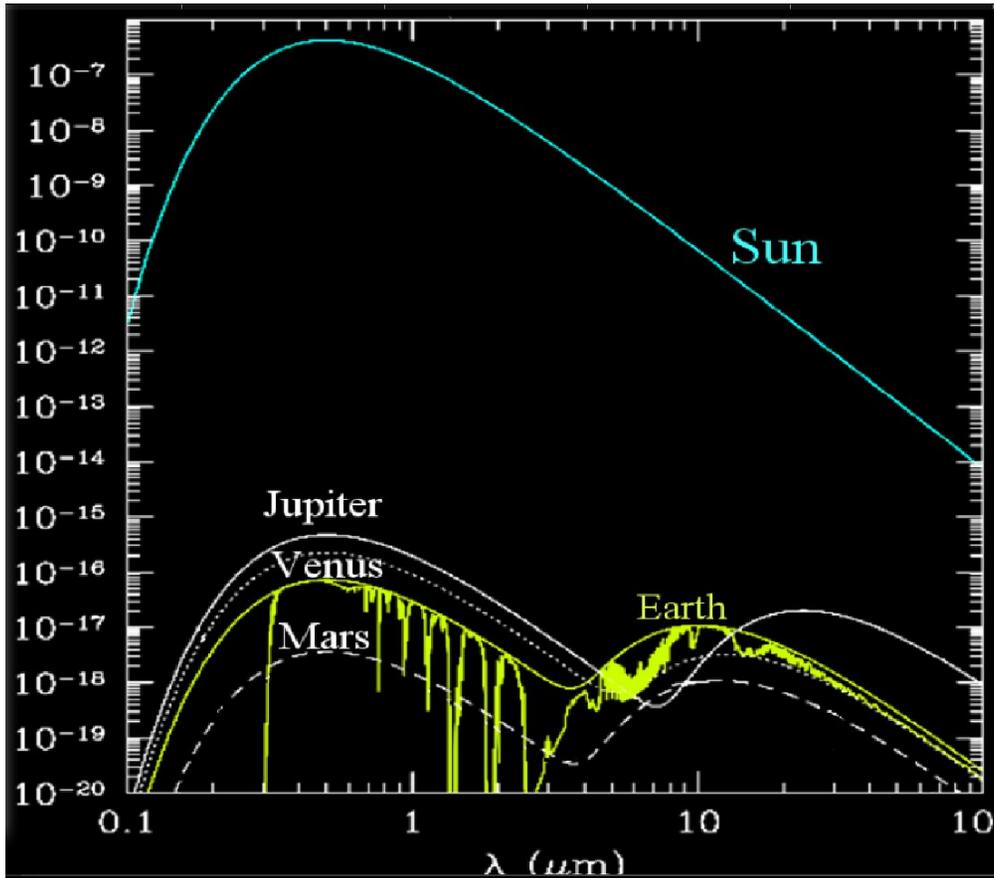
- Detectable?

- Inst. requirements

- Retrieval from data?



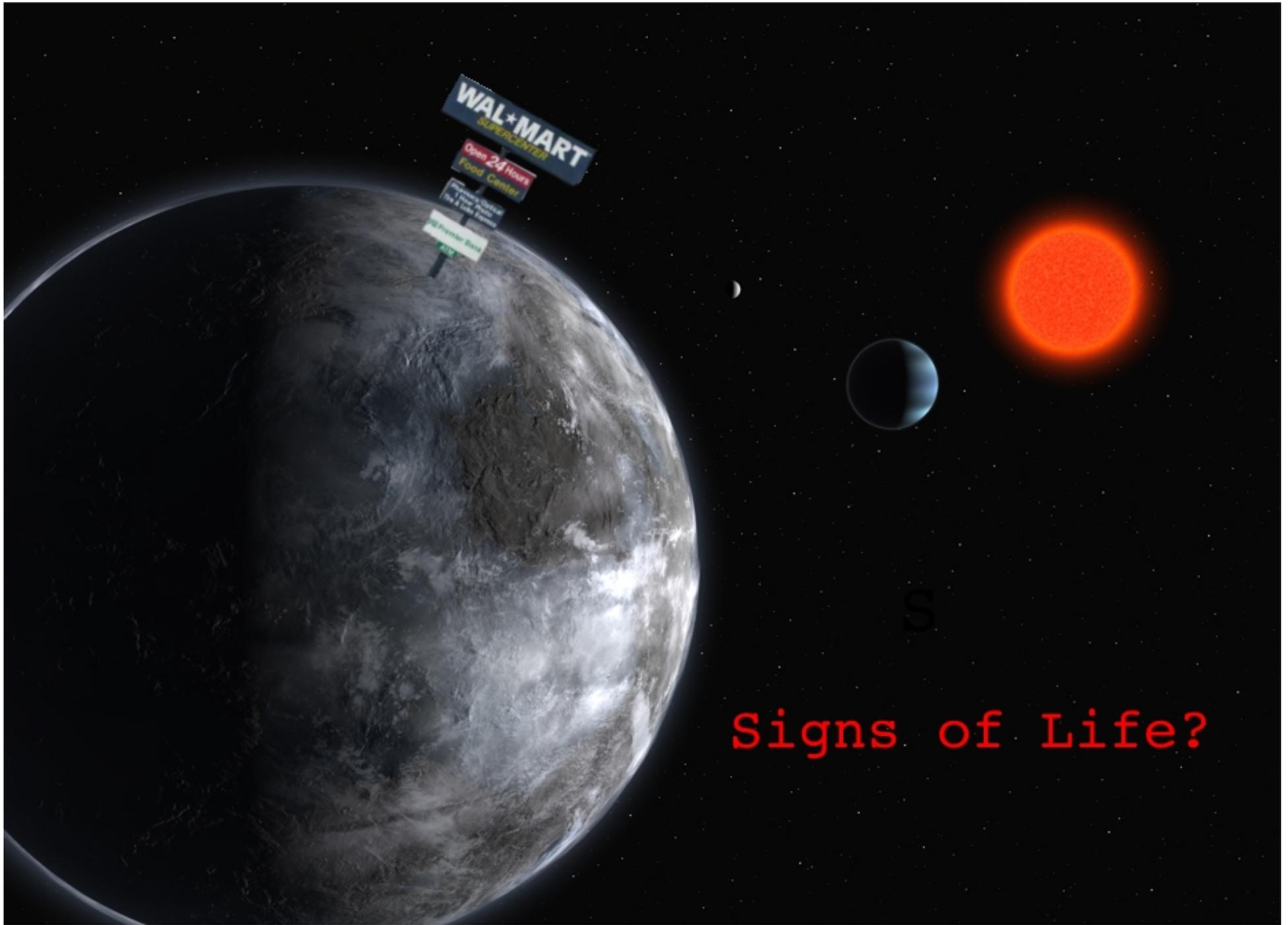
*Udry et al 2007, Selsis et al 2007, van Braun et al 2007, vanParis et al, Kaltenegger et al, ...*



# Gl 581d spectra & star/planet contrast ratio

*Kaltenegger, Mohanty & Segura ApJ 2011*

Spectra (0.1 - 100  $\mu\text{m}$ ): Resolution 150



The Planetary System in Gliese 581

# Summary

- Models: - *WHAT to measure HOW WELL*
  - *to explore the underlying physics*
  - *to have compelling diversity*
- *predict spectra & characterize ( $\lambda$ )*
- *instrument design, data analysis ( $\lambda$ )*
- Earth: a rosetta stone for exoplanets

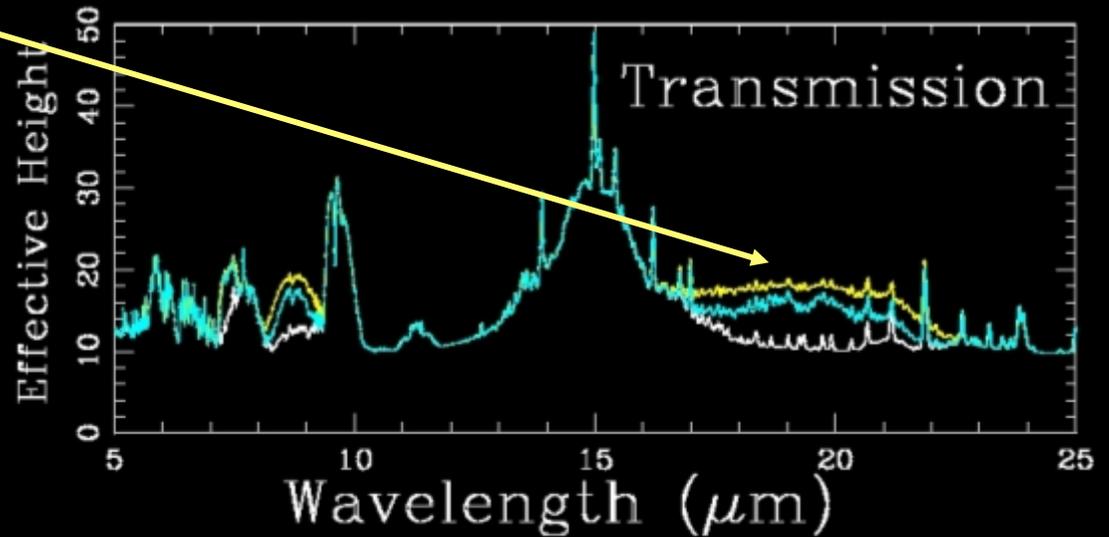
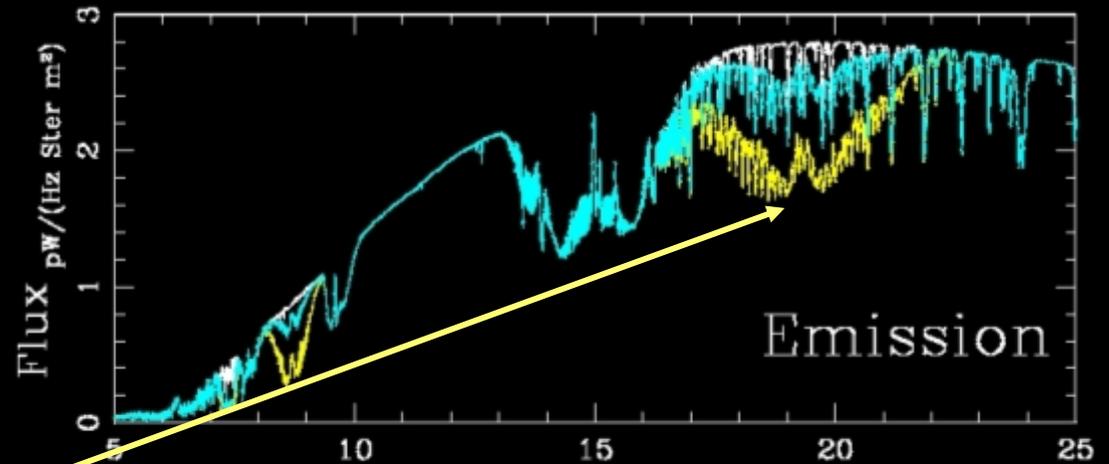
WELCOME TO THE TEAM !!!

e-mail: [lkaltene@cfa.harvard.edu](mailto:lkaltene@cfa.harvard.edu)

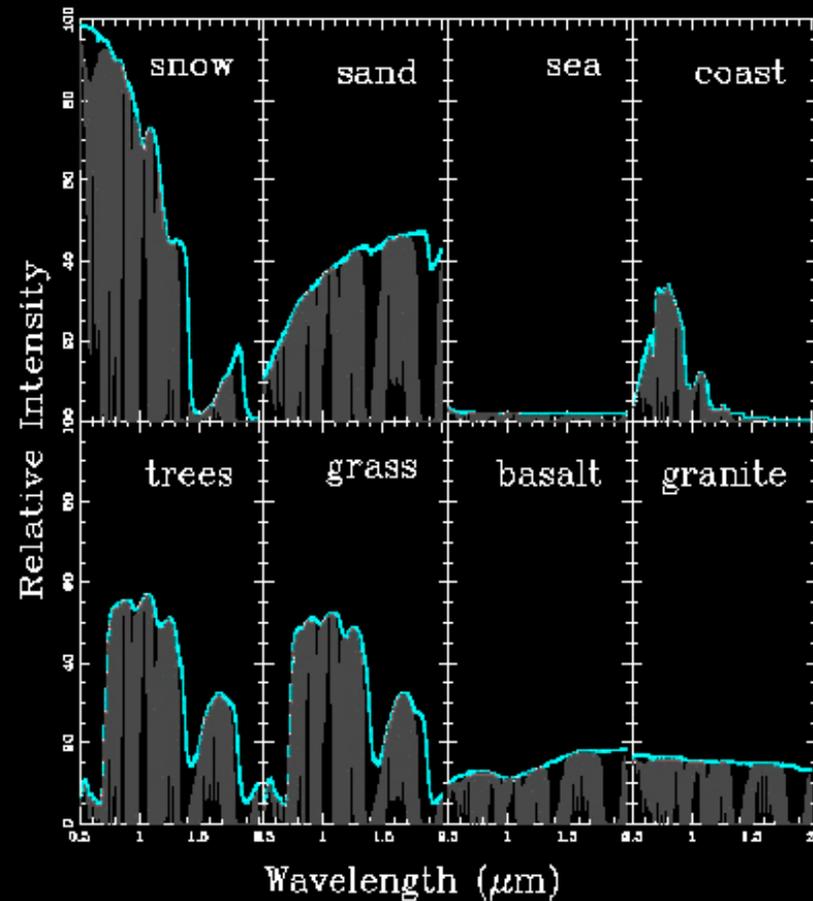


# TEST: explosive exovolcanos ?

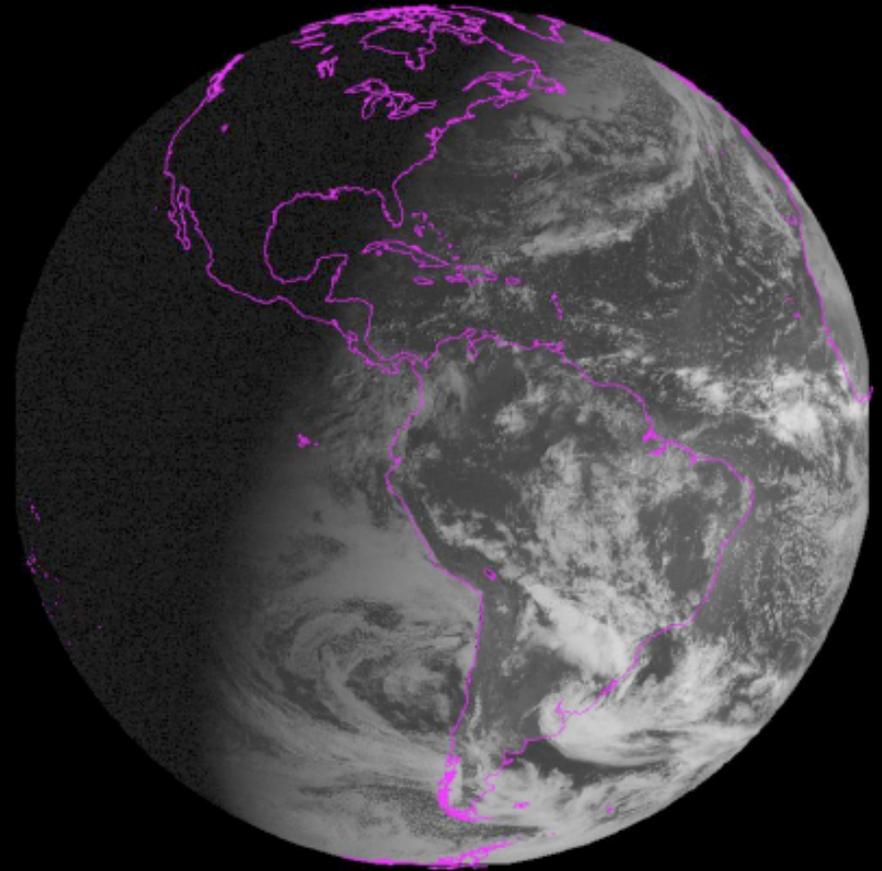
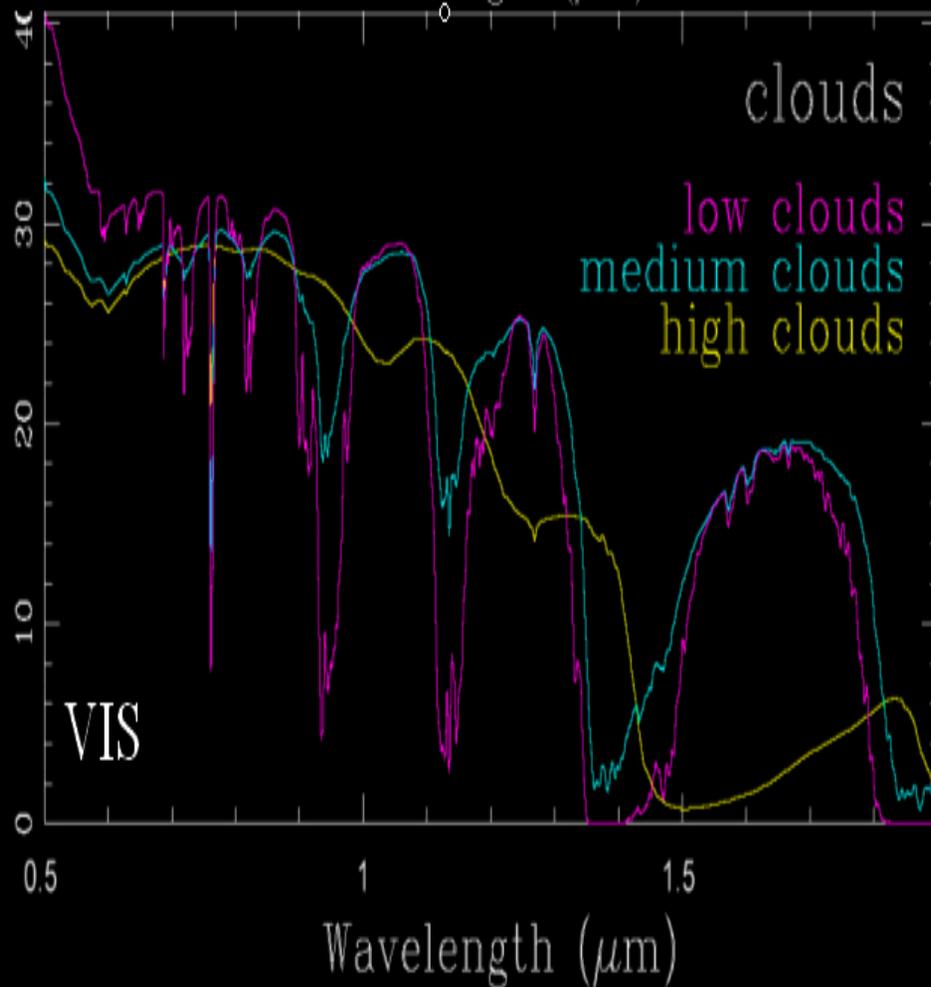
Res = 150, SNR calc. for JWST (pure photon noise, template input for instruments)



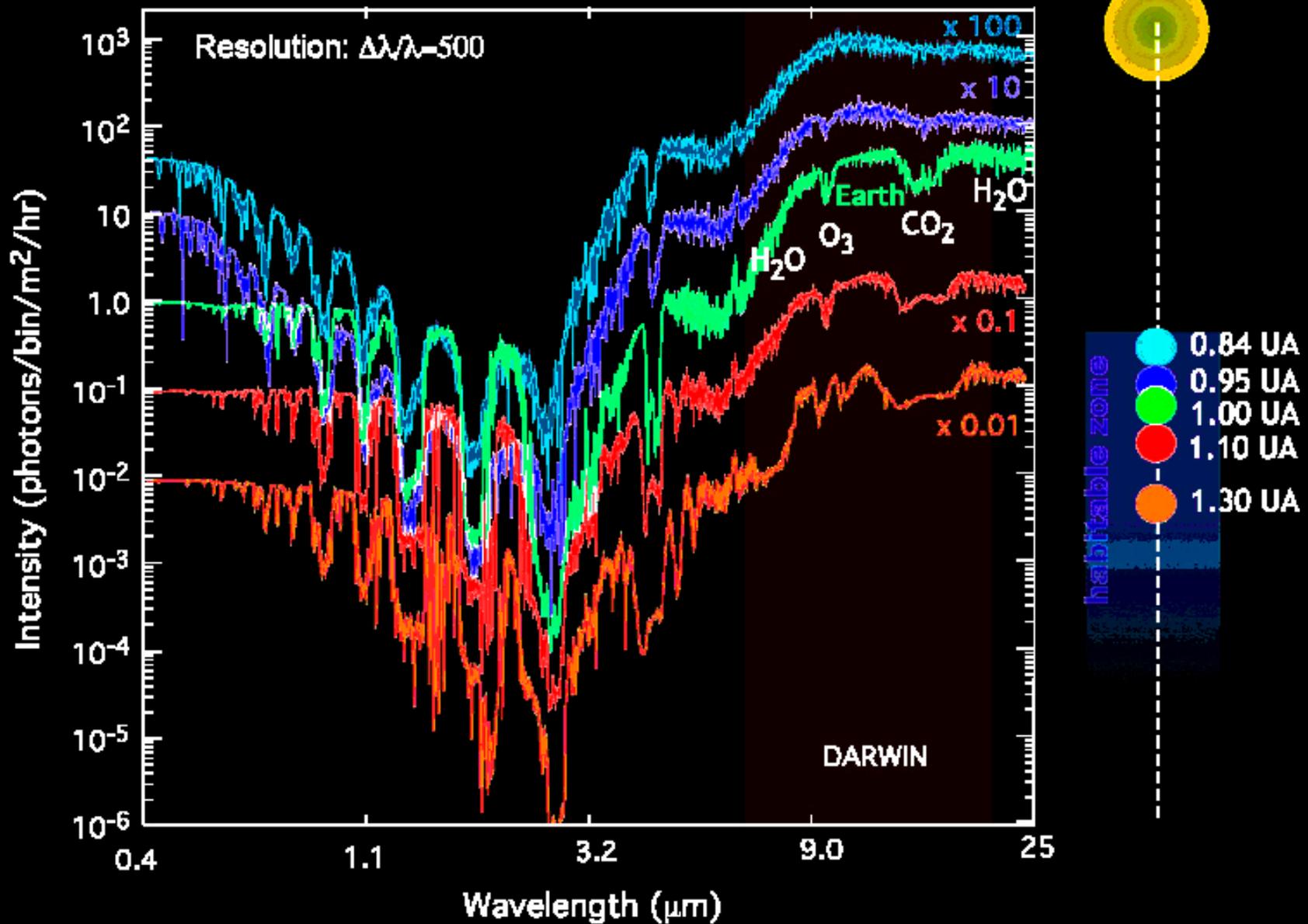
# DETAILS: Albedos & Clouds



# Clouds VIS = bright!: Earth avg 60%

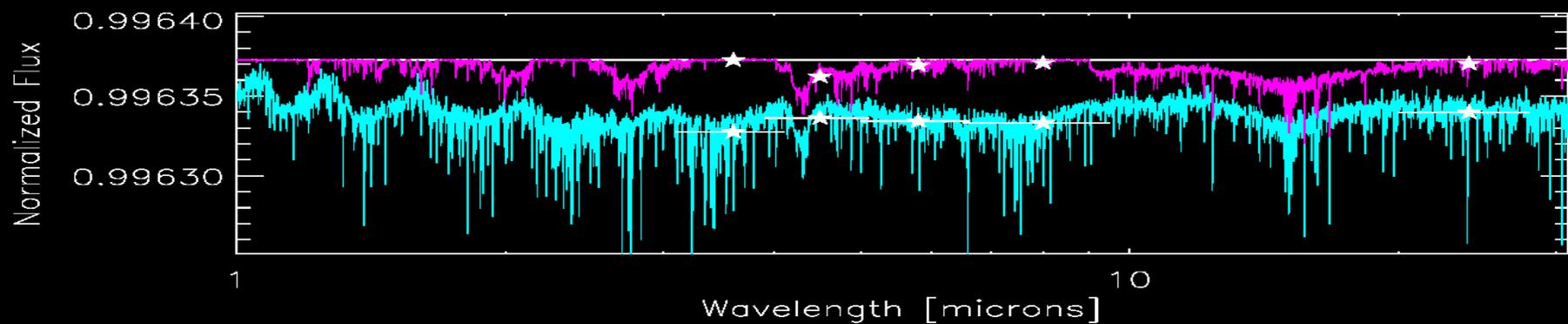
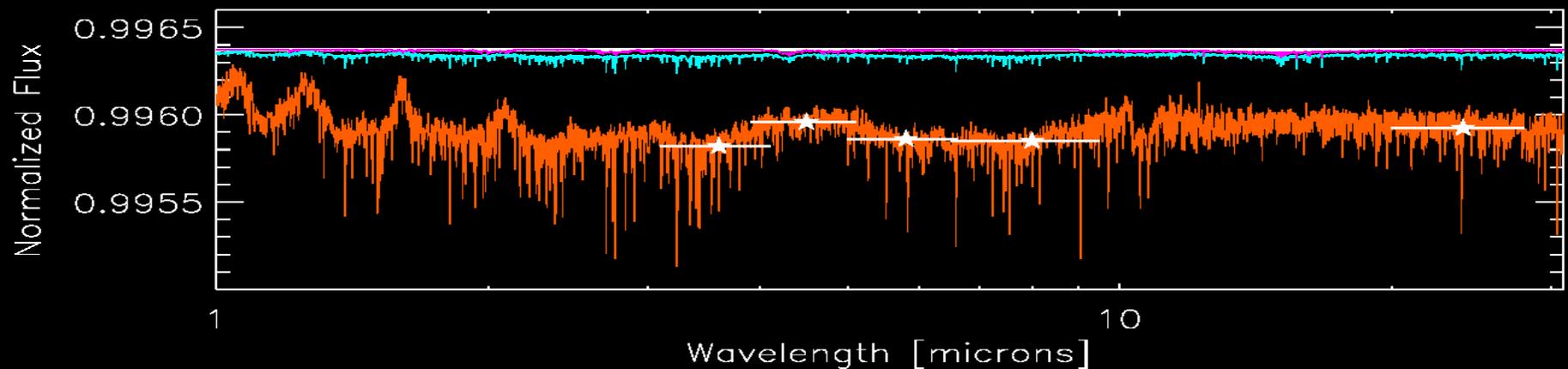


# Earth-like planet across the habitable zone



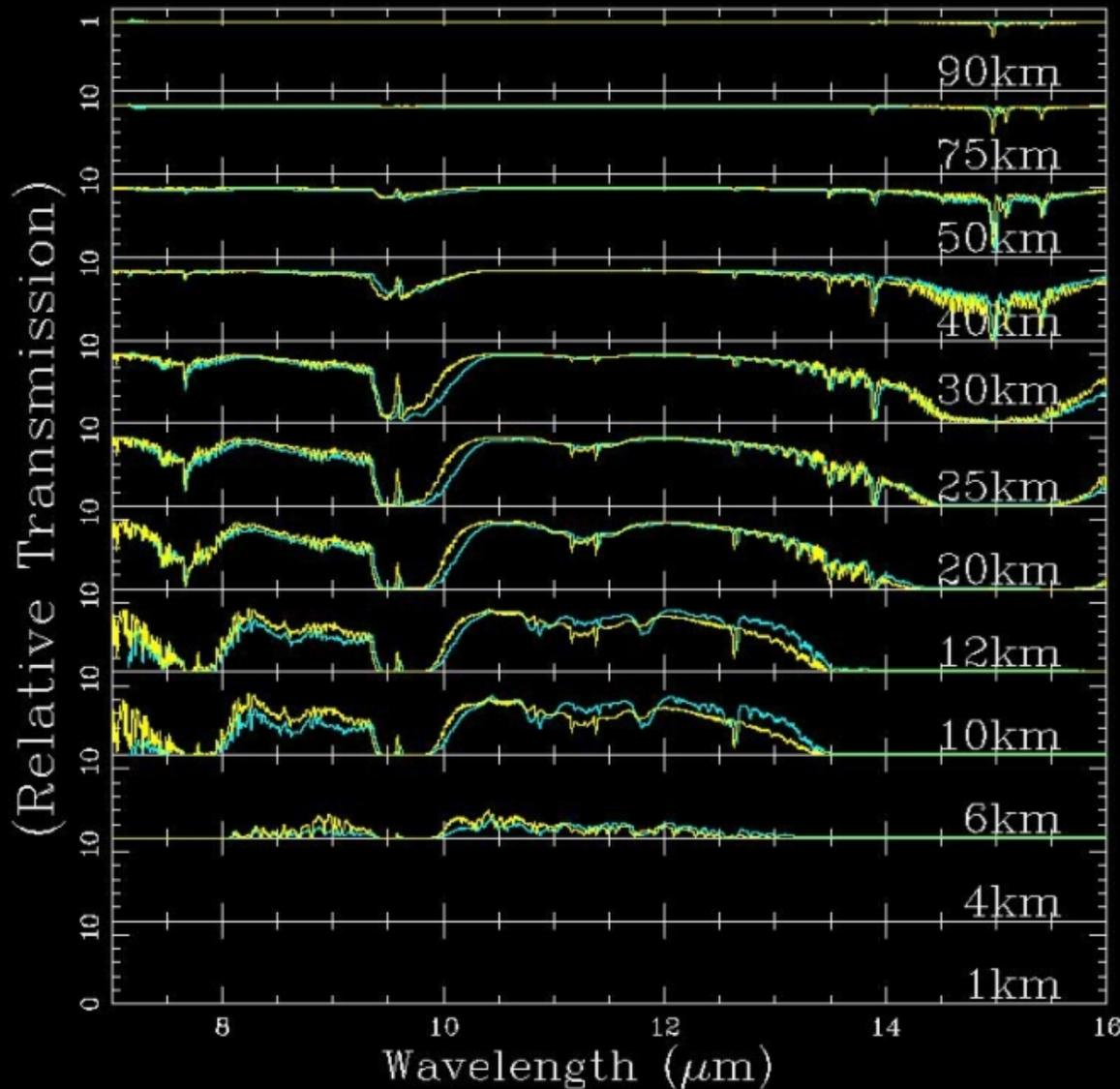
# Distinguishing atm & planet comp

$$h \approx T/(g \mu)$$



*Miller-ricci et al 2008*

# Earth: ATMOS-3: Transmission validation in far-IR



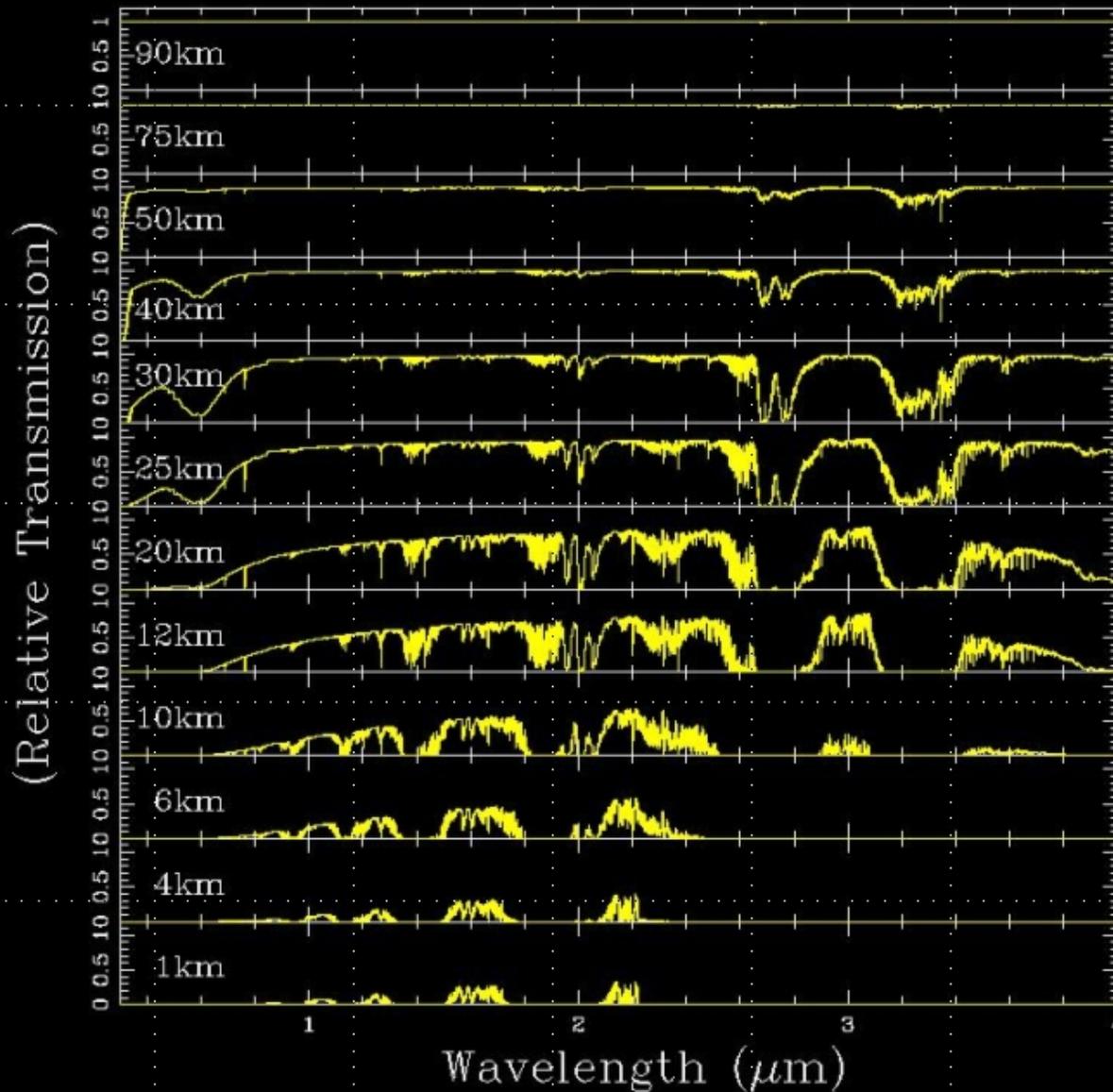
ATMOS-3 transmission of sunlight through Earth's atmosphere, measured with a fast FTS on Shuttle

yellow = model

Fit is close, but line wings are not perfect, perhaps owing to line mixing effects in strong bands.

Note low transmission below 10  $\mu\text{m}$

# Ray-by-ray spectra, visible & near-infrared



Short wavelength range of transmission spectrum.

Note:

- strong O<sub>3</sub> bands
  - at 0.3 & 0.6  $\mu\text{m}$ ,
- weak H<sub>2</sub>O bands,
- strong Rayleigh in blue,
- low transmission < 10 km



## Characteristics

MASS – tectonic, needed ?

RADIUS –

- INTERIOR vs ATM

TEMPERATURE

- Eff vs. surface

ALBEDO

- pattern? clouds, surface)

# Mini-Neptunes

8 - 15  $M_E$

# Super-Earths